TP 4122

SELECTION CRITERIA
FOR HEAVY DUTY ROAD VEHICLE
SUSPENSIONS

PREPARED FOR TRANSPORT CANADA
TRANSPORTATION DEVELOPMENT CENTRE

by

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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17. Abstract

This report presents an overview of the selection process for heavy duty road vehicle suspensions. The principal types of suspension in use today are identified in a state-of-the-art review and the results compiled under the following headings: springing media and configuration, computer simulation and suspension optimization, comfort and ride, test facilities, accident/suspension relationships, handling, and mobility. The report then describes a step-by-step procedure by which a vehicle designer can examine the options available when choosing a suspension system. The process involves: defining the requirements and constraints, reviewing the available springing media, and then working through a flow chart of alternative suspension configurations. Ride control systems and methods of suspension optimization are also discussed.

Conclusions are drawn regarding the most appropriate suspension configurations and springing media for specific vehicle applications. The report emphasizes the benefits of good ride quality in heavy vehicles and recommends the maximum use of computer techniques and test facilities in suspension design.

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17 Résumé

Ce rapport donne un aperçu rapide du processus adopté pour la sélection de suspensions devant équiper des véhicules routiers lourds. Les divers types de suspension couramment utilisés ont fait l'objet d'un tour d'horizon technique qui les a distingués d'après les critères suivants: type du ressort et configuration de la suspension, modélisation et optimisation, tenue de route et confort, installations d'essais, accidents attribués à la suspension, maniabilité et comportement. Ce rapport poursuit en décrivant une méthode systématique grâce à laquelle le concepteur est en mesure d'étudier les options offertes. Cette méthode fait appel aux étapes suivantes: définition des besoins et des contraintes, considération des différents matériaux souples disponibles et examen systématique des configurations de suspension offertes. Le rapport aborde ensuite les systèmes permettant le réglage du degré d'amortissement et traite des méthodes visant à optimiser la suspension.

Des conclusions sont tirées concernant la configuration d'une suspension plus adaptée à certains types de véhicule. Enfin, le rapport souligne l'importance du confort d'un véhicule lourd et conseille au concepteur de la suspension, une pleine utilisation des ordinateurs et installations d'essai.

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APPENDIX A - Review of the State-of-the-Art

SELECTION CRITERIA FOR HEAVY DUTY ROAD VEHICLE SUSPENSIONS

1. INTRODUCTION

This study examines the selection process for heavy vehicle suspensions. The applications concern most commercial vehicles, as distinct from passenger cars, and include straight trucks, highway tractors, semi- and full-trailers, and buses.

The original impetus for the development and refinement of heavy vehicle suspensions, apart from the obvious one of supporting ever increasing loads, was the need for higher speed, and easier distribution of the loads on the road. Protection of fragile loads soon became an important consideration. And for the engineer, distribution of the suspension loads into the chassis is of great importance, strongly influencing, as it does, the chassis concept and design execution.

At the end of the first world war, the pneumatic tire emerged, and interestingly, an engineer of the Goodyear Tire and Rubber Co. held a very early patent on a tandem drive suspension, which strongly resembles today's truck tandems. An illustration of this is reproduced in Appendix A page A3, Figure A1, and in Figures A2 (a and b) the overall effects of pneumatic tires with tandem suspension, as compared with solid rubber tires and single axles, upon sub-soil pressure.

The primary suspension device was the steel semi-elliptic spring, which of course survives and shows every promise of continuing to be the basic means of heavy vehicle suspension.

However the intervening sixty odd years have brought about a long and gradual process of refinement with the objectives of reducing weight, improving ride, and lowering cost.

The steel semi-elliptic spring has some basic characteristics which cause the designer to seek alternative materials and methods in certain circumstances. For example, the inherent friction between the leaves is resistive to energy absorption by the spring. Although damping is desirable, the designer wishes to control the rate of energy absorption and release without the

contraints imposed by the inherent characteristics of the spring. Again, the human frame prefers the natural frequency of a suspension to be close to that experienced during walking (about 1 hertz), but when a semi-elliptic spring is built to reasonable dimensions for a vehicle, it tends to have a natural frequency of approximately twice this, with resulting discomfort. The inevitable long and slender shape of the semi-elliptic spring requires that they be placed between the wheels, and this does not always lend itself to adequate stability.

For these reasons, the designer turns to other materials, which include rubber springs used in compression or shear. These are lightweight and have little internal damping, and sometimes have advantages of configuration. Air springs are popular for carrying fragile loads, and in buses to obtain a low natural frequency. Hydro-pneumatic springs have similar characteristics but are more compact.

These "newer" methods of course offer a whole new array of suspension possibilities which have gone through a process of development parallel to that which took place with the semi-elliptic spring. This process is still going on.

Active ride control really first appeared in heavy vehicles with the air spring. This commonly uses levelling valves to maintain the vehicle frame at a certain height by supplying or removing compressed air in certain circumstances. In the case of buses or highway trailers for example, low natural frequency would imply the need for enormous and unacceptable vertical movement of the suspension unless the height were maintained by continuous adjustment. The air spring requires an external air compressor and a fairly complex and vulnerable distribution system. The most elegant form of active ride control now in use is a hydro-pneumatic cylinder of compact dimensions, in which pump, levelling valves, and variable rate spring are all combined internally in one unit.

The availability of axles, wheels, tires and suspension components makes it possible to select the most appropriate suspension for almost any heavy vehicle, to be used for existing roads, speeds, and highway regulations. The need for further refinement continues, and manifests itself in the gradual introduction of independent wheel suspensions, where they are necessary to solve special problems. These generally are concerned with ride, since an improvement might be expected if the wheels act independently. Considerations of space, for example in a double decker bus with low floors, prevent use of rigid axles and a very wide spring base is necessary for stability.

This study reviews the state-of-the-art and identifies the principal types of heavy duty vehicle suspensions in use today. It is hoped that this summary will provide a useful overview of a rather complex subject, a reference to designers and users, and an indicator of suitable directions for future developments.

2. REVIEW OF STATE-OF-THE-ART

A literature search conducted through the libraries of Transport Canada and Canadian Institute of Scientific and Technical Information indicated that a study of technical papers presented to the Society of Automotive Engineers would cover the subject adequately. The S.A.E., although based in the United States, is international in its scope and membership. Many papers have been presented by experts from Europe, Japan, and Commonwealth countries. Other documentation was used, where it fulfilled a special requirement. Copies of all documentation were reviewed. Abstracts and relevant conclusions were then excerpted. The results were organized as follows:

Springing Media and/or configuration

(i) Steel Springs and Walking Beams
(ii) Fibreglass Reinforced Plastic and Carbon Fibre Springs
(iii) Elastomeric Springs
(iv) Air Suspensions
(v) Active Ride Control Systems

Computer Simulation and Suspension Optimization

Comfort and Ride

Test Facilities

Accident/Suspension Relationships

Handling

Mobility

This study is Appendix A of this report.

3. THE SELECTION PROCESS

The selection process for heavy vehicle suspensions is presented graphically on the flow chart which begins on the following page.

Addressing the problems of selecting a heavy vehicle suspension, it is first necessary to identify the basic requirements and special constraints which apply to the particular case. On the chart, sheet 1, this has been somewhat arbitrarily divided, to indicate that there are basic requirements which apply to all suspensions. In a sense they are all special since each must be checked independently for the application.

Basic requirements are:

- suspend the loads
- position the axles
- absorb acceleration and braking loads

Special constraints are:

- configurational restrictions
- limited vertical space
- low natural frequency
- articulation requirements
- roll stability
- constant height deck
- extremes of load variation
- cost
- serviceability/dependability
- quantity

In going through the selection process and describing the various suspension design alternatives these requirements are kept in view.

3.1 Number of Tires

The process shown on the first sheet is one of iteration, for the engineer. The weights of the vehicle both light and loaded must be identified or estimated. Next, the weight distibution must be determined. With some experience, the engineer knows approximately what size of tires he expects to use, and by reference to the engineering data put out by the tire manufacturers, makes a tentative selection. In most cases the same tire is used throughout for standardization. Duals cannot be used on steering axles because of the tire scrub which would occur and are limited to non-steering axles. The number of axles is then determined from the relationship between the load and the tire capacity, front and rear.

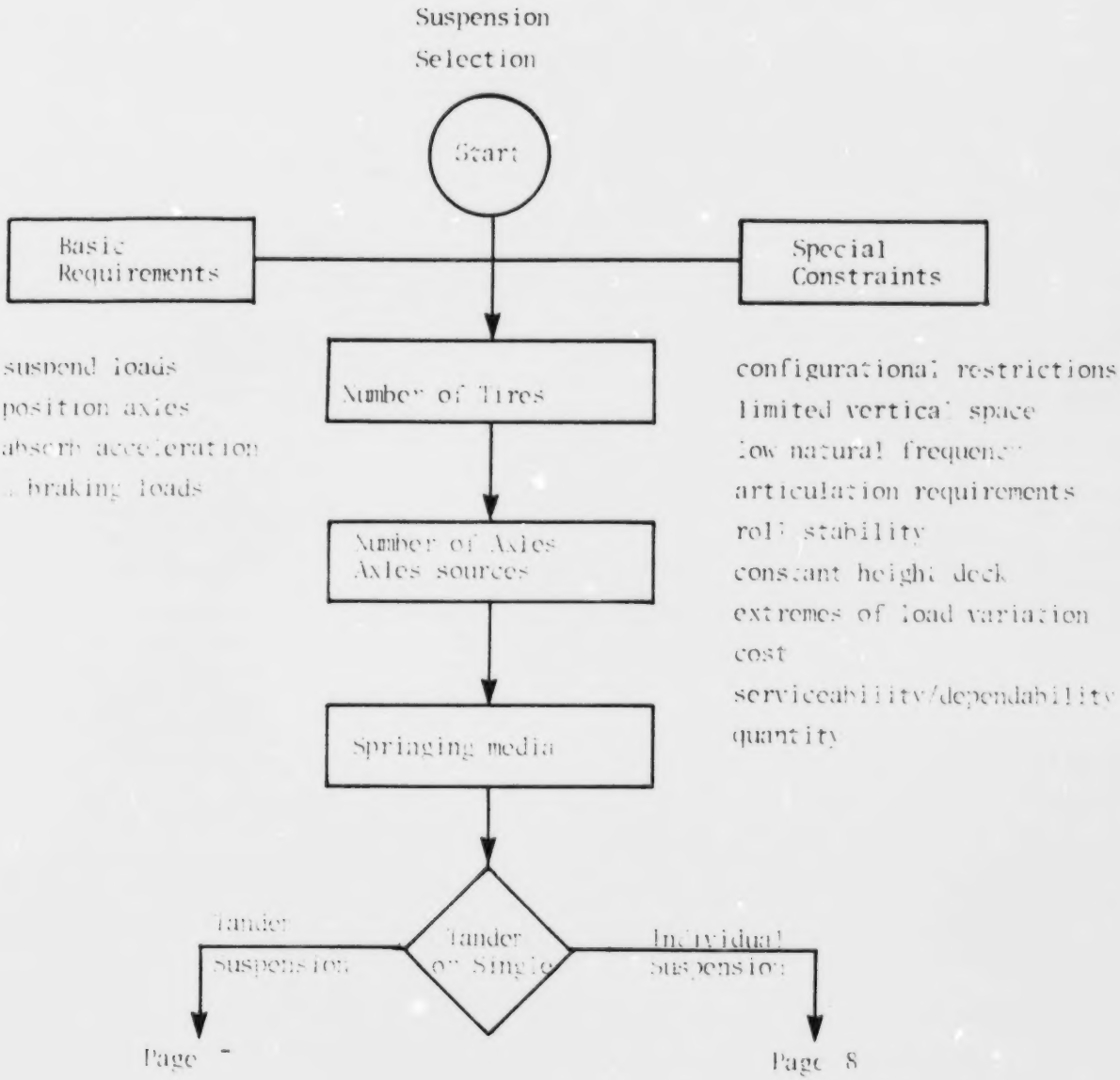


Diagram 1 Suspension Selection

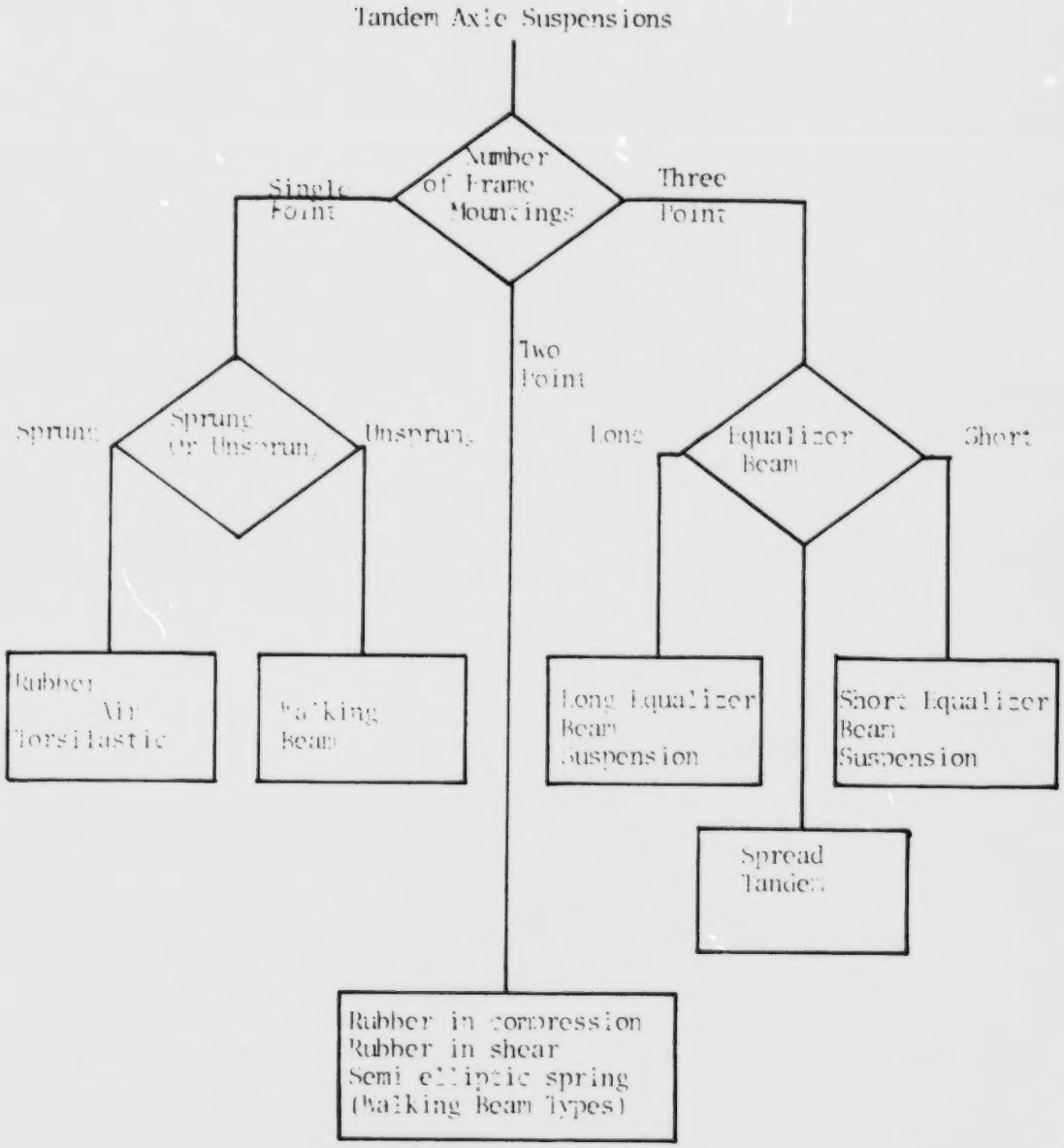


Diagram 2 Tandem Axle Suspensions

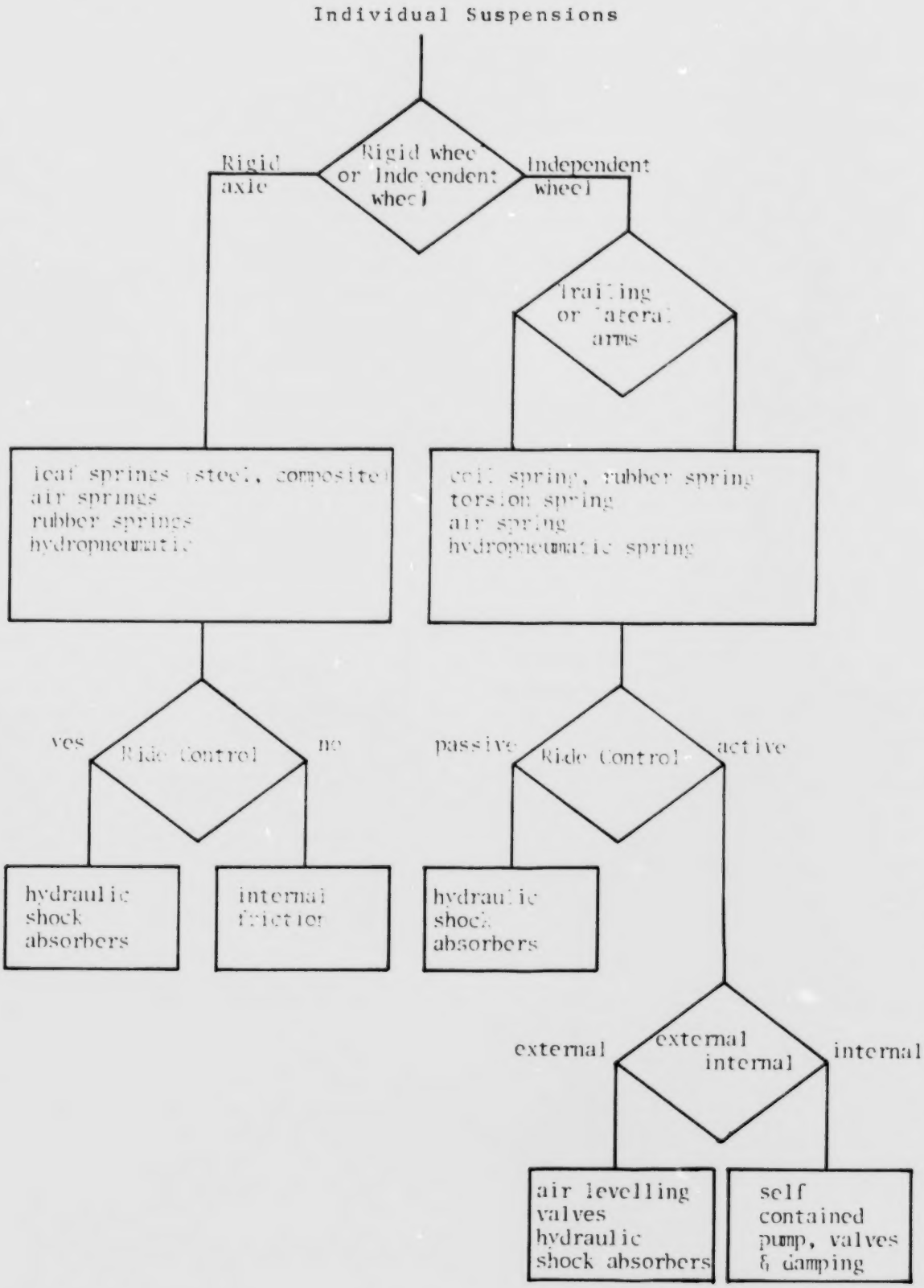


Diagram 3 Individual Suspensions

3.2 Number of Axles

The next step is to check the available axles and make a tentative selection. Of course these may be steering, drive or non-drive, rigid, or involve independent suspension. In the early stages of design, as distinct from simply selecting a suspension of an existing application, this iterative process may go around several times, with various adjustments taking place in the weight distribution, size of tires, and axle selection. At this stage in the proceedings a great deal of investigation of the available components takes place. The principal suppliers of tires, wheels and axles are contacted and eventually are forwarded application sheets which describe the loads and operational circumstances, for the approval of the supplier.

3.3 Springing Media

Assuming there is to be a spring suspension, reference is made to Figure 1 for a quick appreciation of the problems involved. The principal parameters are spring rate and the undamped natural frequency of the spring system. The maximum load is given to be 10,000 kg. At this point the deflection is 100 cm, therefore the rate,

$$k = \frac{W}{d} = \frac{10,000}{10} = 1000 \text{ kg/cm.}$$

It will be recalled that for comfort, the natural frequency should be in the order of 60 cycles per minute. Tne natural frequency in this case is,

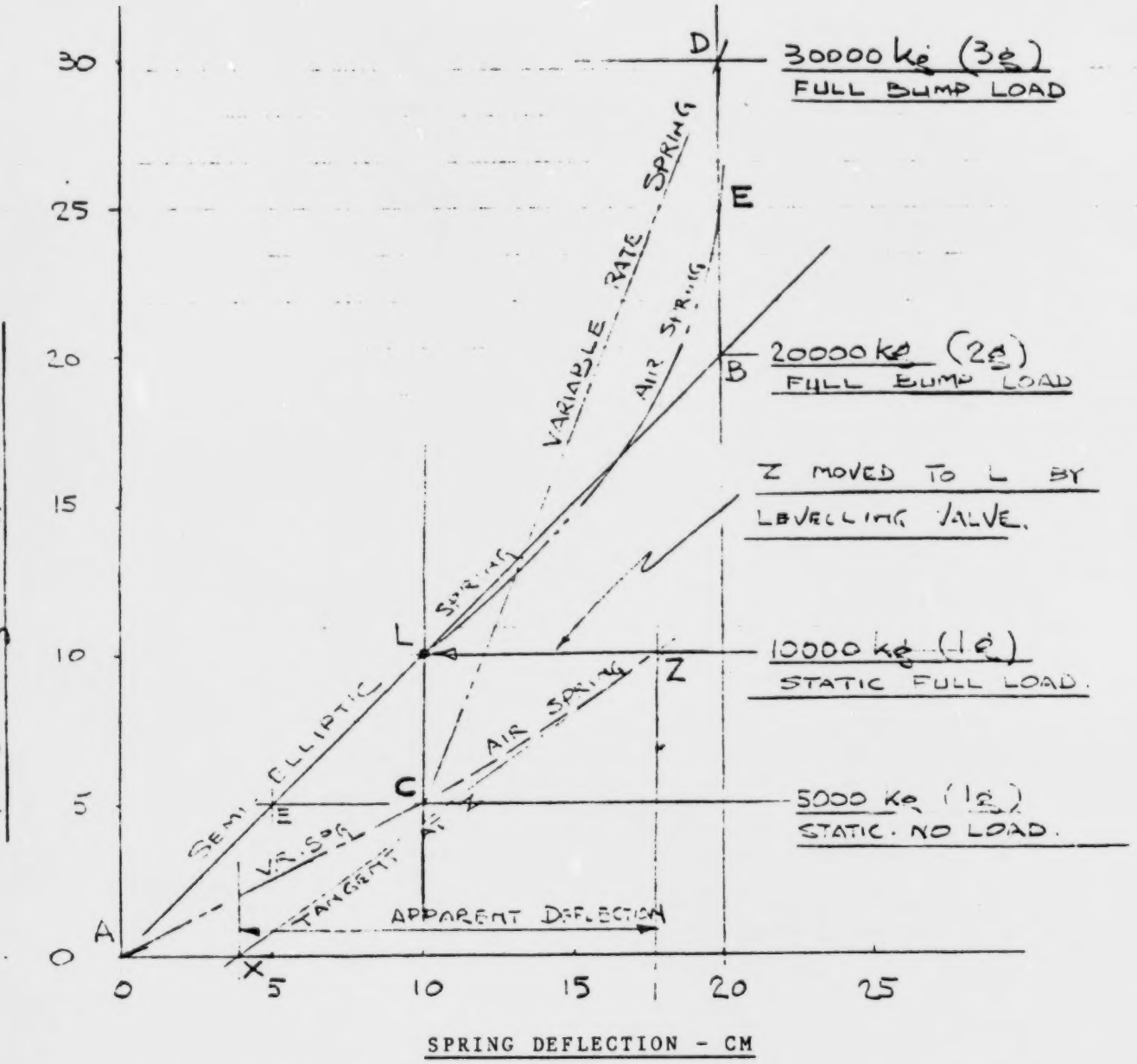
$$f = \frac{60}{2\pi}\sqrt{\frac{k}{m}} \text{ cycles/min.}$$

$m = \frac{W}{g} = \frac{10,000}{981}$ (where $g = 981 \text{ cm/sec}^2$). Subtituting the above values for k and m we have,

$$f = \frac{60}{2\pi}\sqrt{\frac{1,000 \times 981}{10,000}} = 94.5 \text{ cycles/min.}$$

While much higher than our target of 60 cycles/min., this is actually a typical value for a truck suspension. However, it is for maximum load. The spring deflection in the unloaded condition might be 5 cm. Now, note that the spring rate k is the same as before but the mass is now, $\frac{5000}{981}$ and $f = \frac{60}{2\pi}\sqrt{\frac{1000 \times 981}{5000}}$ or $f = 133.8$ cycles/min. In effect this means that when the vehicle is unloaded the frequency is more than twice what we would like and the ride is very uncomfortable.

Now, if we were to go through all the design characteristics for this particular spring, it would be found that 20 cm of deflection (which represents the full bump condition) would cause the stress in the most highly stressed leaves to be very close to the elastic limit. If the 20 cm is increased, the spring might be expected to take a permanent set, which of course would be unacceptable. Or, again, the deflection could be increased by making the spring longer because this would cause the spring leaves to take no more curvature and therefore no more stress. However, the length of the spring might become prohibitive. What we would like to do is increase the deflection at light load, to bring down the natural frequency, but we must pay for it by lack of bump opening at the full load condition. With an application of only 2 g, (20,000 kg), the spring would bump through against the frame. To correct this, we might consider a helper spring which could be an auxiliary semi-elliptic spring, or a rubber spring. Suppose we were able to achieve a rate curve that follows the line ACD. Now we have reduced the natural frequency at light load, main-



Natural Frequency - $f = \frac{60}{2\pi}\sqrt{\frac{K}{M}}$

Spring	Point	K	M	F (cmp)	Condition
Semi-elliptic	L	10000/10	10000/981	94.5	max. load
Semi-elliptic	E	5000/5	5000/981	133.8	light
Variable Rate	0	5000/10	5000/981	94.6	light
Air	Z	10000/14	10000/981	80.0	max. load

Figure 1 Characteristics of Springs

tained it the same at full load, and we have increased the force necessary to push the spring to full bump.

At the risk of over simplification, this should illustrate the constraints which apply to the design of semi-elliptic springs. For freight carrying vehicles, provided that the load is not too fragile, this situation is acceptable. Of course, many developments and refinements designed to improve the performance of leaf springs have been made, but in commercial vehicles it is very hard to get around the limitations.

Air springs offer a solution to this problem. Referring once more to Figure 1, the dashed line AZ and LE shows what might be achieved with such a spring. The curved, ever increasing spring rate characteristic may be tailored by shaping the pedestal (the inner pylon) of the spring which has the effect of altering its area and therefore increasing its supporting capability for the same air pressure, and at the same time the air pressure is automatically increased to support a greater load for the same area. At any point on the curve a tangent such as the line XZ can be drawn and the slope of this line is the rate at the point Z. This point was chosen to be at the same height as point L and represents 10,000 kg load on the vertical scale. However, it will be noted that the apparent deflection is approximately 14 cm instead of the previous 10 cm. The designer might not wish to increase the deflection. In fact this is only "apparent deflection" because by means of a levelling valve we can bring the point Z back to point L, or any other chosen height, and maintain the deck of the vehicle at any height we like. The penalty of course is increased cost and complexity.

In many heavy commercial vehicles, (which are expected to run loaded, not light), the semi-elliptic spring represents the basic low cost design. By virtue of inter-leaf friction, it has inherent damping characteristics. The springs also serve to position the axles in many suspensions. Examples of this will be seen later.

Air springs do not have inherent damping and invariably have to be fitted with hydraulic shock absorbers. These would normally be arranged to control energy release on rebound. They also provide a means of fine tuning the suspension. Elastomeric or rubber springs are used in a variety of ways. Reference has already been made to their use as helper springs. This is shown on Figure A8, (Appendix A, page A-16). The springs shown are known as Aeon springs which are carefully shaped and tailored to provide the correct rising spring rate characteristics, and to some extent this is influenced by air pressure within

the spring. By using two in succession the overall characteristic of the semi-elliptic spring and rubber springs combined can be carefully tailored so that the shock at the full bump condition is largely eliminated. They are much used and very satisfactory in this type of application.

Essentially the same type of elastomeric spring is shown in Figures A10a and A10b (Appendix A, page A21) applied as the principal spring to truck rear axle suspensions, in both a single axle and tandem configuration.

This is an appropriate time to notice the upper and lower control rods which are used to locate the axles with this type of suspension. The upper control arm consists of two diagonal members to locate the axle both laterally and longitudinally, while lower torque rods are positioned to combine with the upper members to resist acceleration and braking torque. A single spring is used on each side of the tandem, with a walking beam to distribute the load to the two axles.

Similar measures are necessary with the air suspension, as can be seen in Figure A12 (Appendix A, page A23). The lower arms and upper torque rods will be noted with the lateral positioning being done by a "track bar" or "panhard" rod. The shock absorbers used with the air suspension will be noted. The rubber suspensions do have some internal damping, but in most cases also require shock absorbers.

In Figures A7a and A7b (Appendix A, page A13) is shown a "torsilastic" concept for a tandem suspension. This rather unique design is fitted with shock absorbers.

Still another approach, this time on a very heavy mining truck, is shown on Figure A-9 (Appendix A, page A18) where a large number of rubber discs are displaced on a guide rod and the rubber acts in compression.

As a medium, rubber has some excellent characteristics, and the resulting suspensions fall somewhere between semi-elliptic steel spring suspensions and air suspensions. They are dependable and long lived but as we have seen, the natural frequency is a function of spring deflection, and with these springs there is no way of providing automatic height adjustment as with air springs. They are of course cheaper than air springs, and more dependable, being free from leaks, require complete control rod systems as do air springs, and are better with shock absorbers.

It will be apparent that any of the basic springing media have certain advantages and disadvantages, and may

appear in many forms, in an attempt to exploit these advantages. For example steel semi-elliptic springs have been refined, first to eliminate or minimize inter leaf friction, with the use of teflon liners, or wafers of antimony, and more recently have appeared with very few or single tapered leaves (see Figure A-4 of Appendix A). They also appear in the form of coil springs, torsion springs, and more lately we are hearing of tension springs, which it is claimed, exploit the energy storage capability of steel to maximum advantage. Rubber springs, as we have seen appear as compression springs, shear springs, and are useful as helper springs. A very interesting use of rubber as an auxiliary to a steel spring is in the Volvo design shown in Figure A-5 (Appendix A page A9).

All of these designs lack capability of automatic height adjustment. The principal difference between automobile suspensions and commercial heavy vehicle suspensions, apart from their size and scale is that automobile suspensions have relatively small load variation, while in commercial vehicles the range is generally very large.

Natural frequency must be kept low, if an acceptable ride is to be produced. Unfortunately a low frequency requires a high deflection. It is entirely possible to design steel springs, or rubber springs, with enough deflection, but if there is a large load variation there is also a large height variation. If the suspension can be designed substantially for one load, this is no problem. Otherwise, it is necessary to provide some system of height adjustment.

Various designs can accomplish this, for example hydraulically adjustable shackles, or air springs used as auxiliaries to leaf springs. Such systems introduce complexity, cost, and maintenance problems.

For most heavy vehicles, which can tolerate a reasonable amount of height variation, the steel semi-elliptic multi-leaf spring or the taper leaf spring, provided with some form of helper spring or cam action to produce a variable rate, is still the best compromise.

For those vehicles which cannot tolerate much height variation such as buses, or any vehicle requiring uniform loading height, some form of automatic height adjustment, or active ride control becomes essential. The principal disadvantage of active ride control systems has been the complexity, cost and maintenance problems which attend

the external systems on which they rely. Air systems involve a compressor, driven by the main engine, reservoirs, and levelling valve systems. The inherent complexities of a hydro-dynamic system are shown in Figure A-19 (Appendix A, page A43). This system developed by Automotive Products Company in England, has been applied to a number of vehicles including a double deck bus on a prototype basis, but apparently the company is not developing it any further. A very elegant solution is shown in Figure A-20 (Appendix A, page A45). This is a self contained pump, levelling valve, variable spring rate hydro-dynamic spring unit, which pumps itself up to the pre-set height as soon as the vehicle begins to move. This unit manufactured by Boge Company of Germany, is used on a variety of high quality automobiles and is becoming available for commercial vehicles.

It seems very probable that the use of composite materials such as fibreglass reinforced plastic (FRP), and carbon fibre laminates may offer the ultimate in specific energy capacity. SAE paper 810325, entitled "Light Truck FRP Leaf Spring Development", describes the development by the Budd Company of an FRP leaf spring which weighed 4.76 kg to replace a steel spring of 20 kg. It states, "the relation which describes specific strain energy capacity is:

$$U = \frac{S^2}{pE}$$

where U is Specific Strain Energy
S is Strength
P is Density
E is Young's Modulus

It can easily be seen that if two materials have comparable tensile strengths, then the lower of the two in Young's modulus and density will have greater specific strain energy capacity. Glass and carbon reinforced epoxies provide over 600 percent of the specific energy capacity of steel. Carbon-reinforced epoxy has slightly more capacity; but when the greater price of one magnitude is considered this advantage is erased." (See below for a summary).

Material	Specific Strain Energy Capacity	Specific Strain Energy Capacity per Dollar
Steel	1.00	1.00
Carbon/Epoxy	6.39	.32
Glass/Epoxy	6.03	3.01

3.4 Tandem vs Single Suspension

As mentioned in section 3.3 on the number of tires the load distribution is addressed at the beginning of a program.

An axle capacity of 10,000 kg is about the most for an over the road vehicle. Axles, both trailer beam axles and driving axles are available in this capacity. Dual tires would each normally have a required capacity of 2500 kg. This is easily satisfied by the 9.00 - 20 or 11.00 - 20 tire. There are of course both larger and smaller units available but this is a typical requirement. A single axle would be used if the total was approximately 10,000 kg, while above this, say 15,000 kg, a tandem would be used. The primary choice of a single or tandem axle arrangement is largely a matter of weight distribution. For most transport type vehicles, height and width dimensions are standardized, usually height = 4.1 m and width = 2.6 m. Frame widths are generally 86.4 cm. Deck heights and dock heights are generally in the order of 1.4 m. There is space within these dimensional limits for dual tires, body structure, and the usual rigid axles. The suspensions are generally mounted to the axles at up to 1.1 m centres, that is, somewhat wider than the frame, to improve stability. This standard practice is deeply entrenched in North America and there is little variation regardless of the springing media or the design of the suspension. This is necessary because the axles are built by one company, the suspensions by another, and the original equipment manufacturer uses off-the-shelf components. Each manufacturer of course provides some latitude. Suspensions come with various spring seat widths, within narrow limits, and the axle manufacturers can supply the axle with spring seats loose, to be welded in place later.

An illustration of a semi-elliptical spring suspension for a single rigid axle appears in Figure 9 (page 24). It is rare to find two of these mounted one behind the other in a tandem arrangement, without some form of equalization system. Similarly with rubber springs, see Figure A-10a and A-10b (Appendix A, page A20), two of the single axle truck suspensions shown would not normally be used one behind the other. The reason is of course that on uneven ground one suspension might carry all the load. A form of articulation is necessary to avoid this problem, and Figure A10b illustrates how the walking beam arrangement is used to accomplish this with the rubber suspension. However, with the Neway air suspension shown as Figure A-12 (Appendix A, page A23) it would be quite normal to use two such single axle suspensions in tandem, but the articulation is done by interconnecting the air chambers. Articulation is perhaps of little importance when the truck or trailer is on a smooth highway, but is essential over ramps, railway tracks, or uneven ground as experienced by a cement mixer vehicle.

It will be perceived that these arrangements are good for trucks and trailers, but they do not satisfy the requirements of buses at all well. First of all, as seen in earlier discussion, it is hard to reconcile the questions of natural frequency and deflection of the suspensions using conventional steel springs. Therefore most buses today use air springs with a levelling system. The demand for low floor height, small wheels, and baggage compartments results from the need to optimize the passenger accommodations. The result is that most suspensions for buses are special.

3.5 Tandem Suspensions

These have been characterized with respect to the number of frame mountings which they employ. A single point frame mounting has one chassis support on the left and one on the right. A two point would have two on the left and two on the right and so on. This is of importance to the chassis designer, since there is a point of inflection above the suspension. Here the bending moment on the chassis which may be "positive" between the front axle and the tandem or single axle rear, reverses and becomes negative and is often found to be the maximum bending moment. The more mountings are provided, the more gradual the distribution of load into the frame, and the lower the bending moment.

3.5.1 Single Point Frame Mountings

a. Solid, walking beam suspensions - The Hendrickson Company builds a suspension, which consists of a large central frame bracket, bolted to the chassis, and a single pivot below with a walking beam connecting to axle brackets at each end. (Figure 2.)

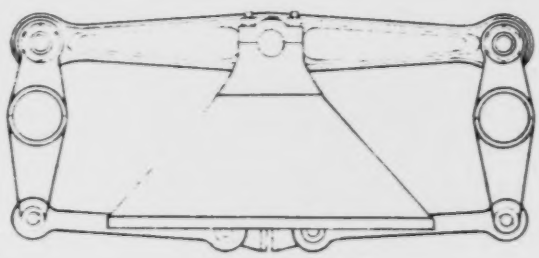


Figure 2 - Solid Mounting Walking Beam Suspension (Hendrickson)

Upper torque rods transmit braking loads to the chassis. Individual wheel movement is provided by making the lower walking beam joints resilient and using spherical or resilient upper torque rod joints. The walking beams have sufficient lateral strength to position the axles in that direction.

Such a suspension would be used only on low speed heavy vehicles. It is adapted to standard frames, depends on adequate mounting height, and provides large articulation. It has excellent roll stability and would be very rugged and dependable if used within its limitations.

It will be noted that, while they combine with the lower torque rods to accept the accelerating and braking forces, the springs themselves rest on the axles using a slipper arrangement. Because the inter leaf friction tends to lock up the leaves and provide a harsh ride, an interesting device has been employed to minimize this problem. This is the use of a rubber cushion between the axles and the ends of the springs. This is said to provide the necessary resiliency to give a good ride.

b. Sprung, Rubber - The suspension shown in Figure A-10b, (Appendix A, page A21) again shows the use of A arms to position the axles laterally and to take braking loads. The single point spring seat has its mounting spread over a long length of the frame to distribute the load. The ends of the walking beams are free to move and restraining lugs are all that is necessary to keep the walking beam in position. It is otherwise completely free, and can be lifted out if the frame is jacked up. Lower torque rods with spherical ends complete the system. This tandem will have a fairly small deflection therefore quite a high natural frequency. It is rugged, simple and dependable.

c. Sprung, Torsilastic - The torsilastic suspension shown on Figure A-7a and A-7b (Appendix A, page A13) is a unique type of two point suspension, since the rubber is used in shear. Walking beam and spring are combined, and apart from this it appears that the axle positioning is done in the usual way, with the walking beam ends attached to the axle through brackets, and an upper torque rod arrangement or A arm arrangement which is not shown.

d. Sprung, Air - Illustrated is an earlier Hendrickson design of single point air suspension mounting. It is questionable whether it is a single point mounting, since the air spring supports the A bracket which holds the walking beam, and this bracket is stabilized by two drive pins located ahead of and behind the air spring on each side of

the frame. Note that as usual upper torque rods are used to take the braking forces, but the lateral positioning of the system must be done by the drive pins since neither A arms nor a panhard rod are used. (Figure 3)

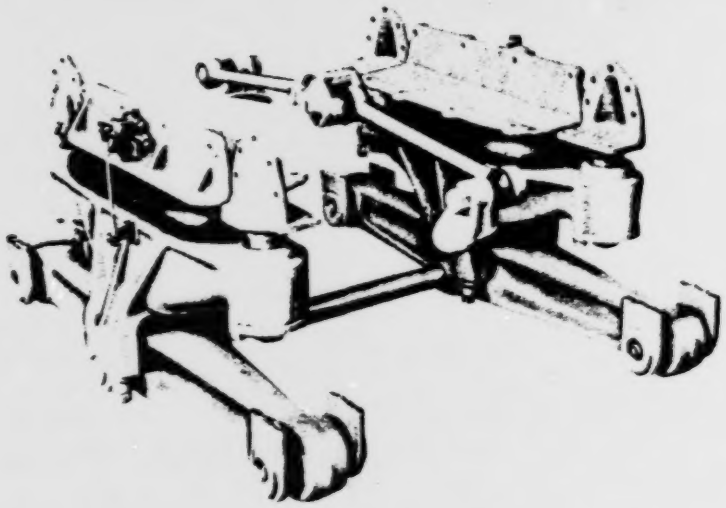


Figure 3 - Single Point Air Suspension (Hendrickson)

3.5.2 Two Point Suspension

a. Rubber in compression, walking beam - This is known as a rubber load cushion type. The tandem is positioned laterally by the rubber springs alone. This supports a frame bracket, which again takes a walking beam connecting the tandem axles. Upper torque rods take the braking reactions as usual. This will be a very hard riding suspension. It will be somewhat better than the solid mounting type, since the rubber will supply some resiliency. (Figure 4, next page)

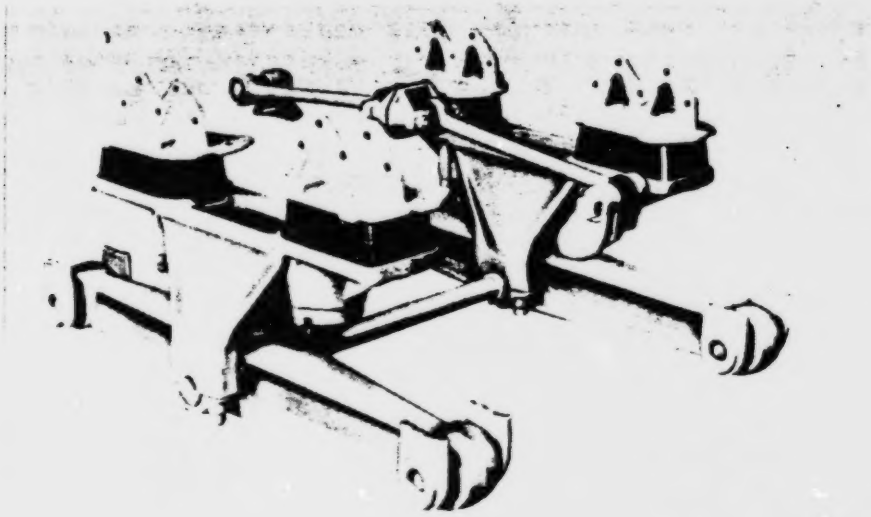


Figure 4 - Rubber in Compression walking - beam suspension (Hendrickson)

b. Rubber in shear, walking beam - Once again the suspension is positioned by the rubber units, which this time act in shear and possibly give a little better ride. The deflection is necessarily small. (Figure 5)

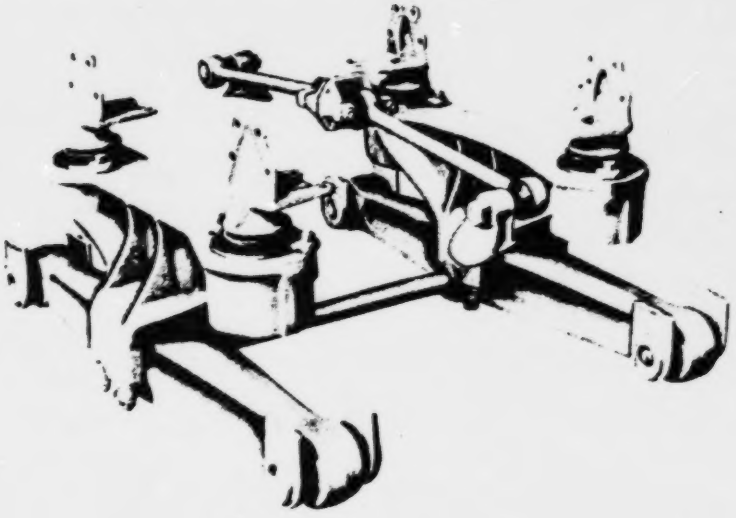


Figure 5 - Rubber in shear, walking beam suspension (Hendrickson)

c. Semi-elliptic spring, walking beam - The Hendrickson RUEA-340 suspension is illustrated in Figure 6 and shows a four point suspension which is much more commonly used than any of the three mentioned earlier. The semi-elliptic spring is interesting because it has an extended leaf which gives a good ride at light load, with the main part of the spring coming into action only after the spring deflects beyond the light load. The suspension is quite typical with forged aluminum walking beams connected to axle brackets, and upper torque rods to take the braking reactions. As in all these suspensions the spring walking beam arrangement locates the system laterally.

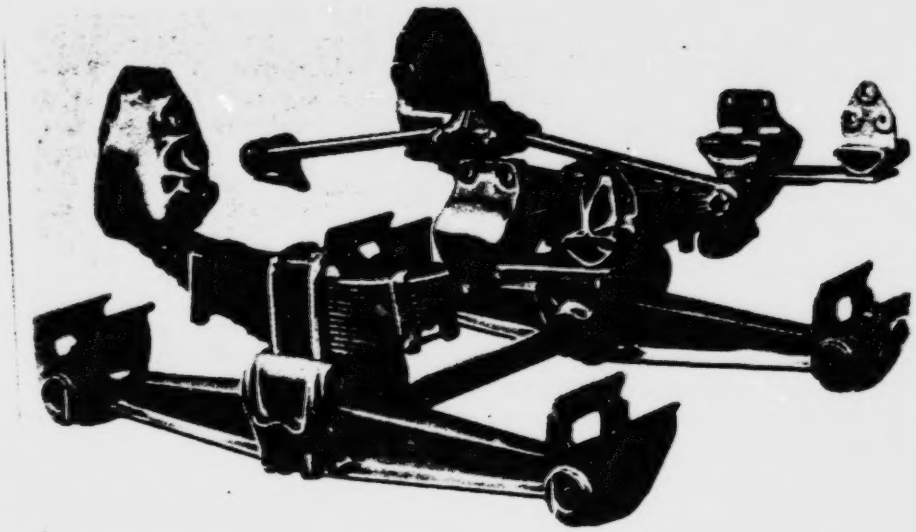


Figure 6 - Semi-elliptic spring,walking beam suspension (Hendrickson)

3.5.3 Three Point Suspension

Suspensions

a. Short equalizer beam - The Freightliner three point suspension shown in Figure A-3, (Appendix A, page A4) is a typical modern semi-elliptic spring three point suspension. Intended for a truck drive tandem, it is arranged so that the drive line slip (of the inter-axle drive line) is held to a minimum. The friction in the spline is sufficient to affect ride, and Freightline have made an effort to minimize this effect. Note amongst other things the reduced number of leaves (5), the slipper ends, and the fact that only four torque rods are used. These torque rods must take the braking loads into the frame except those transmitted through wind up of the springs. When this happens, the equalizer beam tilts (up at the front and down at the back due to the braking load transfer, and a stop for this purpose has been provided).

The tandem shown in Figure A-4 (Appendix A, page A6) is another interesting example. This suspension uses four taper leaf springs, arranged to provide a two stage action. This is done through cams in the equalizer and support brackets. As in the previous example there are only four torque rods two of which are of fixed length, and two are adjustable for alignment. The suspension is positioned laterally by the springs themselves.

b. Long equalizer beam - This is not really a three point, but is rather a two point suspension, but it is included here for comparison with short equalizer beam type. The long beam serves to connect the rear of the two springs in tandem and because of its length permits more axle articulation. Because the rear ends of the springs instead of a front and a rear are interconnected, it also serves to equalize torque or load transfer. (Figure 7)

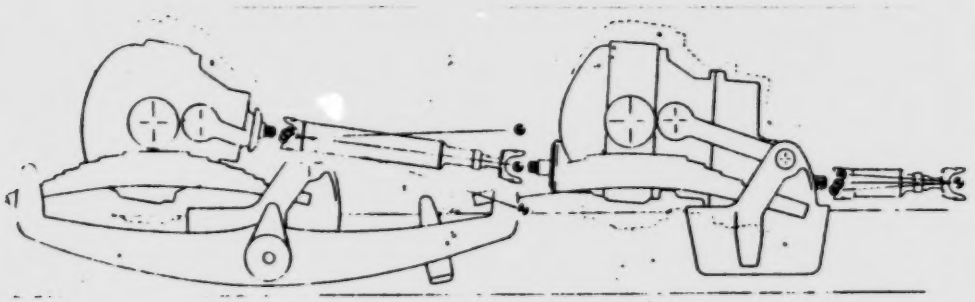


Figure 7 - Long equalizer beam suspension

3.6 Individual Suspensions

The term individual has been used to include single axle suspensions, and independent wheel suspensions, as distinct from tandem suspensions.

3.6.1 Rigid Axle

Leaf Spring Suspension

a. The basic type of leaf spring suspensions is the multi-leaf, semi-elliptic version, with an eye, usually at the forward end, which may be rubber bushed or bronze bushed, with a straight pin to secure it. Sometimes the pin is threaded through the bushing.

None of these arrangements is universally successful in heavy vehicles. The main problems are noise, caused by clearance both radially and axially, wear, and lubrication. The threaded design is intended to prevent side slap between the eye and the bracket, but this results in a curious wear pattern due to the partial rotation of the eye as the spring goes up and down.

At the rear end, the spring may be supported by a shackle, which is pinned to the spring and to the frame bracket, and has similar wear and lubrication problems to the front eyes.

A slipper end may be used instead of a shackle, at the rear of the spring. This is noisy but has good wear properties.

As explained in the section on "springing media" (paragraph 3.5) the designer is usually trying to obtain the lowest natural frequency consistent with supporting the load and with the space available for deflection (or constraints on deck height variation.) Also, the stress due to braking must be checked, because the axle is bolted directly to this type of spring, and braking torque is absorbed by winding up the spring into a flat S-shape. The resulting stress is frequently the controlling design feature and may be high enough to cause permanent set in the leaves.

The solution is to use a slipper end at both ends of the spring and a torque rod system is used to take the braking loads. (Note also the use of rubber helper springs on the TIMBREN application, following page.) (Figure 8)

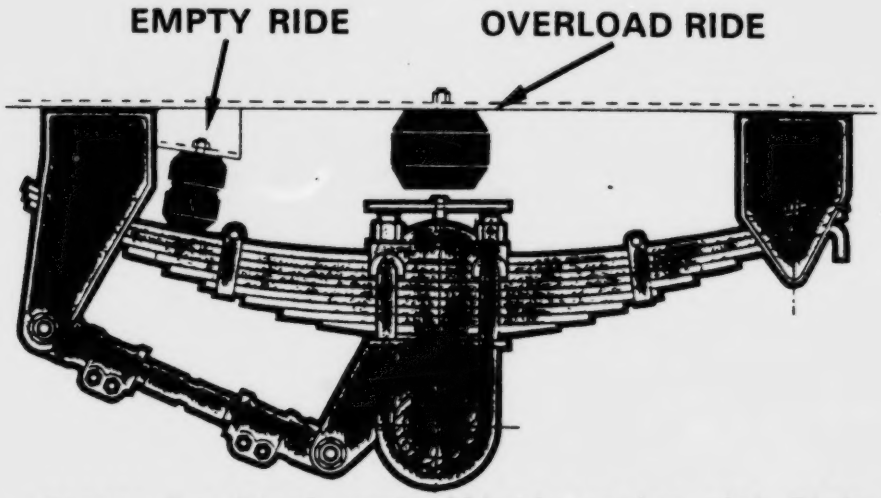


Figure 8 - Steel semi-elliptic spring with Timbren rubber helper springs

The torque rod is placed low down, consistent with providing adequate ground clearance. The slipper ends still carry some load due to wind-up, with this arrangement, because there is no upper torque rod. The lower the torque rod, the less the spring wind-up. However, the braking stress in the spring is reduced to manageable proportions by this means.

Spring wind-up during braking can cause serious steering problems if the steering arm ball is not placed very close to the center about which the spring rotates during wind-up. The axle is rotated slightly during the braking, being bolted to the spring. The steering arm ball, being held in place by the drag link therefore moves relative to the axle. This causes the wheels to steer and cause the truck to "pull" to the right. Similarly the ball must be placed to follow the same arc described by the axle as the spring deflects vertically, or a wandering tendency will be present. Figure 9 illustrates this type of suspension used in a Transport Canada crash tender.

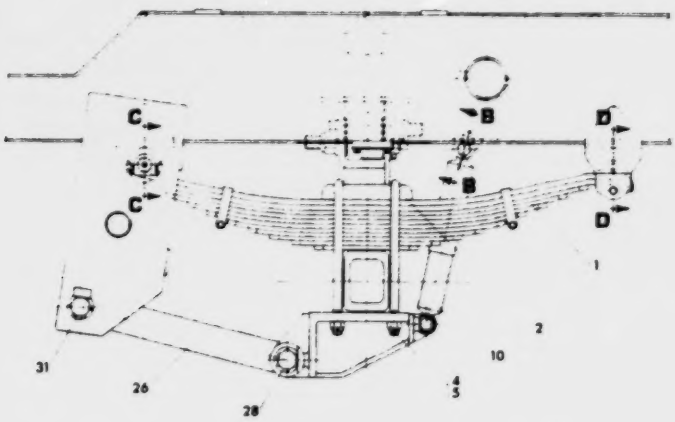


Figure 9 - Single axle, semi-elliptic spring suspension for a heavy crash tender.

The design of semi-elliptic springs is partly art, partly science. The detail design is quite complicated and involves metallurgy, stress analysis of upper and lower leaves during deflection and braking assembly stress, life calculations (they all break eventually from fatigue, if operated through enough cycles), estimates of damping due to interleaf friction, variable rate effects due to shackle angle or cam effect of slipper ends (as the spring shortens, its rate varies as the cube of the length). And besides, they are usually expected to position the suspension laterally.

b. Air Springs - For single axle installations these are essentially similar to tandem installations described previously. The rolling lobe type is used almost universally.

Torque rod systems are used to position the axles and take the braking reactions, and "track bars" or "panhard rods" are used for lateral positioning or else A-yokes which combine both functions.

Shock absorbers are used to damp the system, which has no inherent damping.

The systems are available for truck/bus drive axles, tag axles, and trailer axles. They are equipped with levelling valves which maintain deck height constant. They are favoured for carrying fragile loads. They are inherently expensive since they involve a compressed air system, more maintenance and higher first cost.

c. Rubber springs - The Aeon type rubber springs, also made by Moog and U.S. Rubber are used as helper springs for semi-elliptic steel spring suspensions.

The Chalmers suspension, both tandem and single axle type are shown in Figure A-10a and A-10b (Appendix A, page A21). Features to note are the torque rod system and upper A-arm for combined tracking and brake reaction, the snubber system to control rebound, and, not shown, the usual requirement for shock absorbers.

These suspensions can give quite a good ride under load, have a variable rate characteristic, and are less expensive than air systems when the compressed air components are considered. They are very simple and relatively maintenance free.

3.6.2 Independent Suspensions

Independent wheel suspensions are "a must", if ride is to be optimized. The reason is to be found in the relationship between sprung and unsprung weight. This is a simple relationship involving inertia, and should be as large a proportion of "sprung" to "unsprung" as possible. A rigid axle is at an immediate disadvantage since both wheels and the interposing axle beam are affected by any wheel displacement over a bump, which effect is reduced by one-half with independent suspension.

For stability in roll, especially with a high centre of gravity, the suspension should be as far outboard relative to the body, as possible. This constraint leads to a careful selection of suspension medium, especially for steering axles, since wheel turning angle further intrudes on the available space between the wheels.

Suspension systems such as air springs and hydro-pneumatic systems lend well to these space limitations. Coil springs may be used with a concentric shock absorber in the familar passenger car front wheel layout.

The use of lateral arms facilitates the wheel cut angle of steered wheels and is thus commonly used on front suspensions, while trailing arms are frequently used on rear suspensions because of the increased stability which they impart to the vehicle.

This can be readily understood by reference to Figure A-15 (Appendix A, page A33). For stability, a low roll centre is desirable. This is the point about which the body will tilt under the action of centrifugal force. The distance between the roll centre and the centre of gravity acts as leverage for the pull-out torque and influences the roll of the body in curves.

a. Coil springs - The coil spring is used in both passenger automobiles and railway trains successfully. It will be apparent however that it is not very simple to fit a self-leveling system, therefore the usual difficulty of providing low natural frequency within the space constraints imposed on the deflection will apply.

The coil spring is friction-free and therefore requires shock absorbers.

It may be used as an auxiliary to hydro-pneumatic springs.

b. Air springs generally fit very well into the space envelope, especially for steering axles. They are used for buses with independent suspensions, mostly in European designs. Figure A-16 (Appendix A, page A34) shows an interesting arrangement used by M.A.N. to provide exceptionally high stability.

c. Hydro-pneumatic springs - This type of suspension is perhaps best known for its application in the Citroen car. But it has been used very successfully in very heavy vehicles such as the WABCO HAULPAK off-highway trucks. The semi-elliptic spring, with high frequency and hard ride, severely limits hauling speed over the rough terrain often encountered. See Figure A-18 (Appendix A, page A-42).

The term "Active Ride Control" has been applied to such systems, which implies the use of a means of pumping the system to a predetermined height, a variable spring rate, constant frequency and a levelling system which helps with stability in roll. It can be used to make the body lean into curves, and has an inherent damping control system.

The Automotive Products Company in England applied this to a number of vehicles including Rolls Royce cars, ambulances and a double-decker city bus, with excellent results. However the inherent complexity of the external system used Figure A-19 (Appendix A, page A43) might be the principal reason that it is not being pursued past the prototype stage.

Such systems, if used with rigid axles, imply the use of control rod systems such as have been described in connection with air and rubber springs.

The integral single and twin chamber system Figure A-20, (Appendix A, page A45) combines all the features of an active ride control system in one compact unit.

Figure 10 (next page 28 and figure 11 page 29) shows concepts of front and rear independent suspensions for an intercity bus, using hydro-pneumatic springs.

d. Torsion springs - These springs are more difficult to fit than coil springs, requiring anchors and guides, but do not use very much space if there is room to place them along the frame for lateral arm suspensions or across the frame for trailing arms. Otherwise the same problems of natural frequency, deflection and damping requirements are involved.

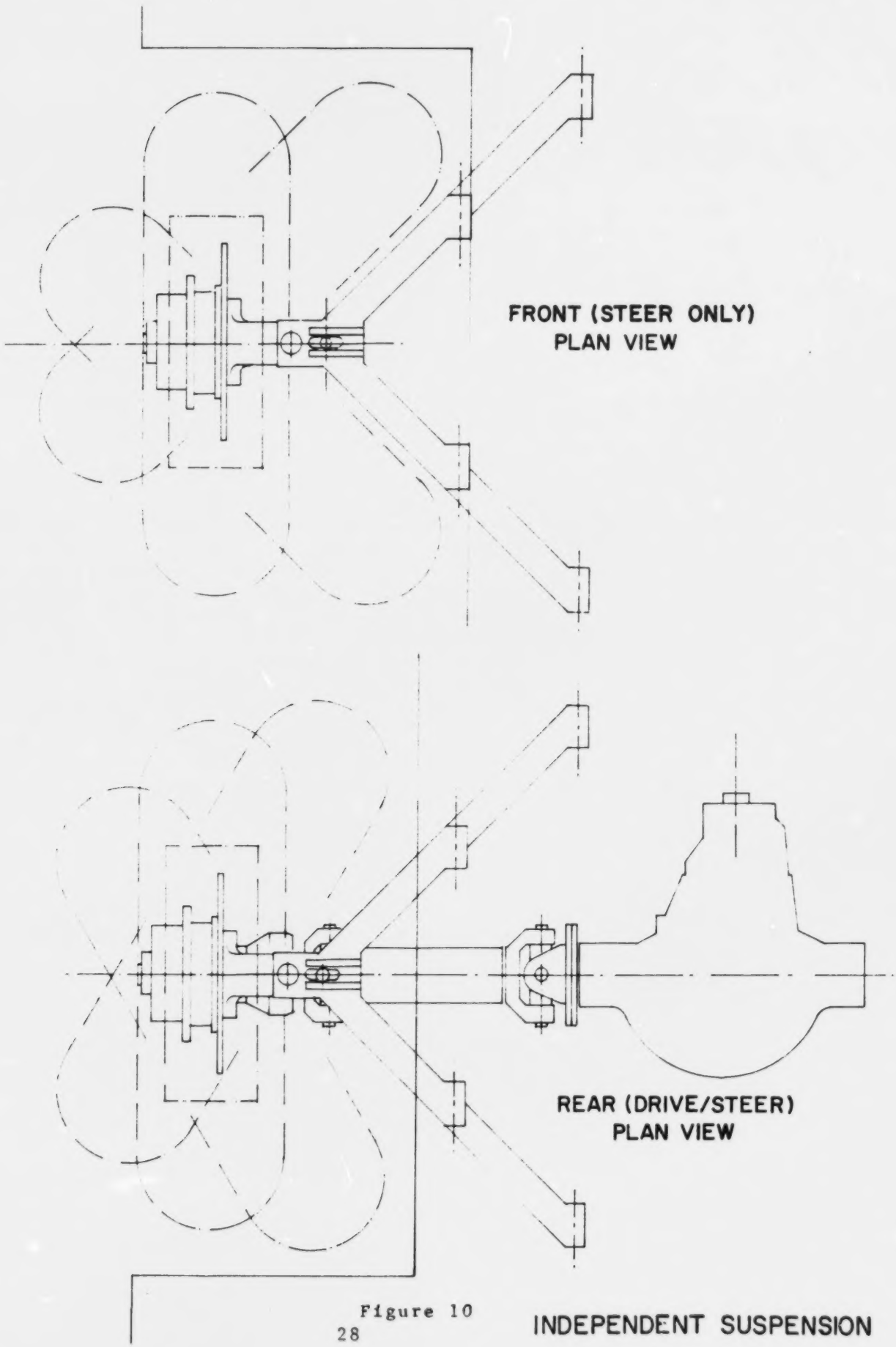


Figure 10

INDEPENDENT SUSPENSION

1. UPPER "A" ARM
2. LOWER "A" ARM
3. TIRE
4. RIM
5. BRAKE DISC
6. OUTER WHEEL BEARING
7. INNER WHEEL BEARING
8. HUB
9. OUTBOARD SLIP DRIVE SHAFT
10. DIFFERENTIAL
11. BALL JOINT
12. CONSTANT VELOCITY UNIVERSAL JOINT
13. HYDROPNEUMATIC SUSPENSION UNIT
14. VEHICLE BODY

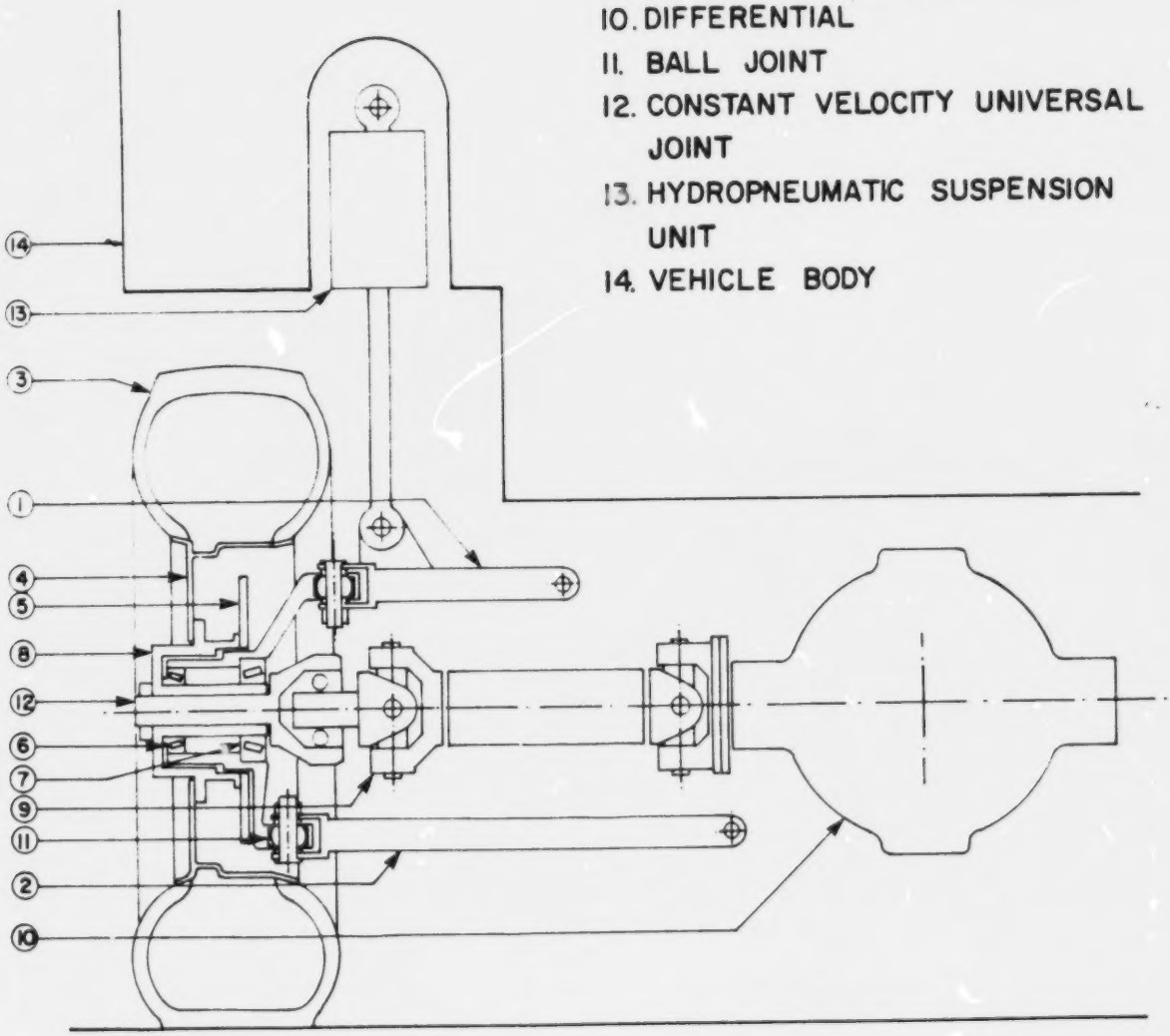


Figure 11

INDEPENDENT SUSPENSION
DRIVE/STEER AXLE

e. Rubber springs - The AEON rubber spring has been applied to an independent trailer trailing arm suspension, and fits well into the space envelope as well as air springs, coil springs, or hydro-pneumatic suspensions.

The previously described problems associated with natural frequency and deflection apply. There is no easy way to regulate the height.

Torsilastic suspension is used by American Eagle in their intercity buses on both front and rear suspensions. They quite correctly make the point that this system (Figure 12 below) controls sway. As always adequate deflection to produce a low natural frequency must be provided, and this implies a large amount of wheel travel.

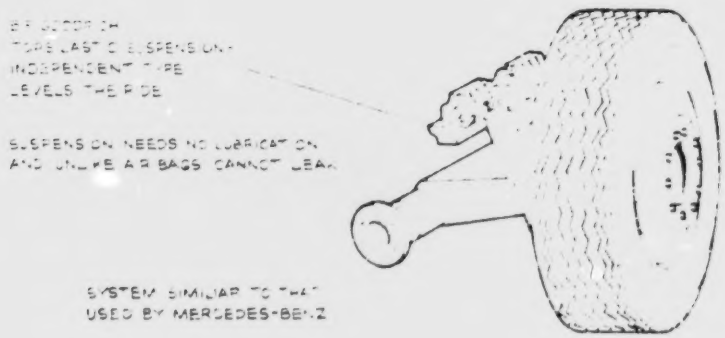


Figure 12 - Bus torsilastic independent suspension

3.7 Ride Control

In describing the various systems of suspensions, the various shortcomings have been mentioned. These are tolerable if economy is of over-riding importance. When they are less than tolerable, a special design is selected which will cope with the problem. Hence, the use of air springs on trailers and buses; the use of hydro-pneumatic suspensions on WABCO mining trucks; the use of torsilastic independent suspensions on American Eagle buses, and so on, even though these systems are inherently more expensive than the faithful semi-elliptic spring.

The term "ride control" generally refers to the use of shock absorbers. In a broader sense, it may be used to describe the advantages of some of the more sophisticated suspension.

For example, the general use of upper diagonal links and panhard rods, (or track rods) has the characteristic that the high location causes lateral displacement or sideways shock to the body when a bump is encountered. Independent suspension eliminates this problem.

Shock absorbers are high maintenance items. But the use of frictionless springing media, such as coil springs, air springs, and rubber springs makes them necessary in most cases. In buses they are a necessity, and certainly are required on at least the front suspensions or any truck so equipped.

It is not unsual to fit shock absorbers to tandem suspensions of the walking beam type, due to the high articulation.

Where the more conventional springing media are used, monotube shocks should provide better life expectancy than the better known double-tube shock absorber. Both contain both gas and oil, with the damping being controlled by the passage of oil across the rebound piston through spring loaded valves. In the double-tube design the piston is in the inner tube and being smaller, its seals are more subject to wear. The cushioning gas is in the outer tube. Once the seals are worn, damping control is lost.

The monotube design uses the same principle but the piston is much larger and its seals have a longer life. The gas is separated from the oil by a floating piston.

The hydro-pneumatic type of spring Figure A-20 (Appendix A, page A45) combines the shock absorber feature and the springing medium in the same unit.

4. VEHICLE SUSPENSION OPTIMIZATION

The first approach to the design of a heavy vehicle suspension is fairly elementary. Selection of the basic parameters such as spring rate, deflection, and natural frequency are readily accomplished and a range of possible values is established.

Input data require tentative knowledge of the system configuration, and includes sprung and unsprung weights, centre of gravity location, braking forces and roll and cornering forces. Also required are the output criteria, such as allowable stress, natural frequency, and the design load factors. Some of these data may be highly variable and may be subject to later experimental confirmation.

From then on, having roughed out the design, things become more complicated. Optimization must be carried out, and this has, in the past, frequently been done by trial and error. This is a very slow and expensive procedure.

Basically, the objective is to provide the optimum ride. It is necessary to establish as soon as possible, a relationship between customer usage, laboratory testing, and proving ground trials, with respect to strength and durability.

The characteristics of the suspension reflect directly in the handling of the vehicle and its dynamic behaviour during maneuvers and braking.

The frame may have been assumed to be rigid. In fact, it is elastic, and this must be taken into account. It may set up its own vibrations and resonances, which may prove intolerable or cause premature failure.

Measurement of loads and stress levels on both the suspension components and the frame may be suprisingly different from early estimates.

Modern techniques using computer analysis can be used instead of the old trial and error methods. Mathematical modelling of the suspension in its principal degrees of freedom is the first step. The principal parameters can then be varied and the resulting output excitations can be compared with the requirement criteria. The models do not necessarily have to be very refined, in terms of representing the final behaviour of the vehicle in exquisite detail. It is simply an evaluation tool used to show trends toward optimization of the ride and vibration characteristics of the suspension/vehicle system.

The random loads acting on components can also be described in terms of simple parameters, by direct measurement with modern instrumentation, and reproduced in laboratory fatigue tests.

There are not many laboratory test installations suitable for heavy vehicle suspensions. One of them is located at the University of Michigan and is described in SAE paper 800906. It is capable of testing single axle and tandem suspensions. This permits simulation of road conditions and fatigue testing.

Proving grounds provide controlled conditions for final testing, and are designed to provide concentrated road conditions representative of those which will be encountered on a random basis in actual service. This permits relatively rapid identification of problems, which may be hard to accomplish under service conditions, due to environmental and traffic problems and the difficulty of locating suitable terrain for testing.

5. RECOMMENDATIONS AND CONCLUSIONS

1. Steel is still the major springing medium for heavy commercial vehicles and is likely to continue to be, because it can be used to combine high energy density properties and low cost with the capability of the spring to at least partially position the suspension.

2. Steel may be challenged by composite materials, particularly FRP, where weight saving is paramount. It has a much higher energy density than steel.

3. Air springs are widely accepted for fragile load protection and good ride but involve a cost penalty. They could be threatened by hydro-pneumatic springs, which are more compact and can be made self-contained.

4. Rubber springs have wide application as helper springs and have attained limited acceptance as primary springs. They are also used in some special applications (mining trucks, bus torsilastic springs.)

5. Shock absorbers of the mono-tube type appear to have advantages over the double tube type in terms of longer effective life.

6. Hydro-pneumatic springs appear to have excellent possibilities for wider use in heavy vehicles, to improve the ride of trucks and trailers, as well as buses. They combine special qualities of ride control and compactness.

7. Independent suspensions are feasible for both steering and drive wheels in heavy vehicles, and are recommended for heavy vehicle applications to improve ride.

They are regarded as essential in future bus applications such as a double-decker bus where height, headroom and underbody clearance are serious constraints.

8. In the development of heavy vehicle suspensions, maximum use of computer techniques should be made to speed up the design process and reduce cost. Heavy vehicle suspension test rigs are necessary, in addition to proving grounds, to optimize suspensions.

9. Good ride in heavy vehicles may have untold benefits in reduced driver fatigue, fewer accidents, longer vehicle life, and increased speed-made-good.

APPENDIX A

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STEEL SPRINGS AND WALKING BEAMS

1. HISTORY OF TRUCK SUSPENSION - TANDEM SUSPENSIONS

Edward D. Hendrickson, SAE # 690096

ABSTRACT

This History of Tandem Suspensions outlines the problems encountered by early four wheel solid tire trucks. It covers the evolution to pneumatic tires and then the addition of the third axle. It illustrates the many different types of suspensions developed, as well as the corresponding drive and trailer axle assemblies. It then illustrates that the economics of the dual axle concept are still current today. (Figures A1, A2a, A2B, page A-3)

2. DEVELOPMENT OF A NEW TANDEM TRUCK SUSPENSION

Ira Maxon, SAE # 650627

ABSTRACT

This paper introduces a new tandem suspension suitable for trucks or highway tractors, with advantages in superior ride and lower weight. Multileaf steel springs are used in conjunction with unusually effective cams, producing a two-rate spring with the higher rate four times that of the lower rate. Newer materials such as nodular or ductile iron are used extensively. Rubber bearings are used to eliminate lubrication. Specific data are given with respect to selection of materials as well as stresses imposed in service.

The outstanding characteristics of the Model LWH Page & Page tandem walking beam suspension are the superior ride and light weight. Cams are used to increase the spring rate by 4 times.

Other design comcepts include, no lubrication points, easy serviceability, and good durability. The springs are not used for structural purposes, only for springing.

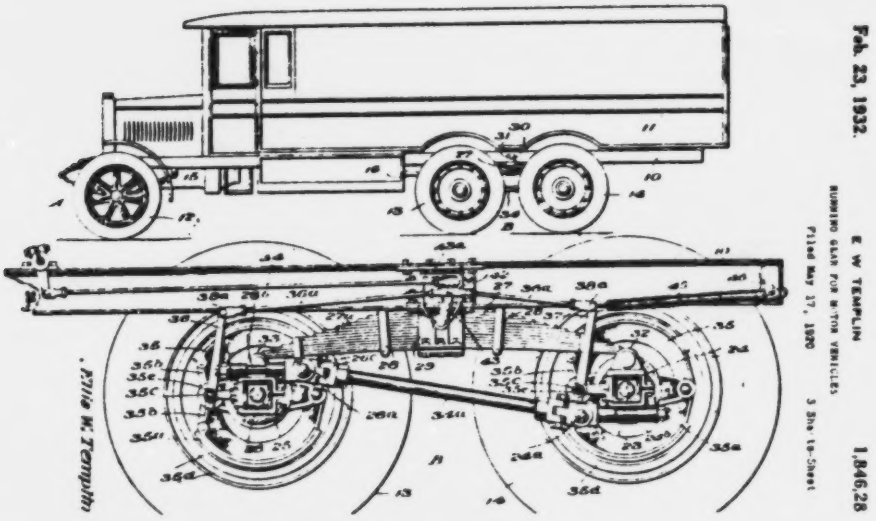


Figure A1 The Original Design

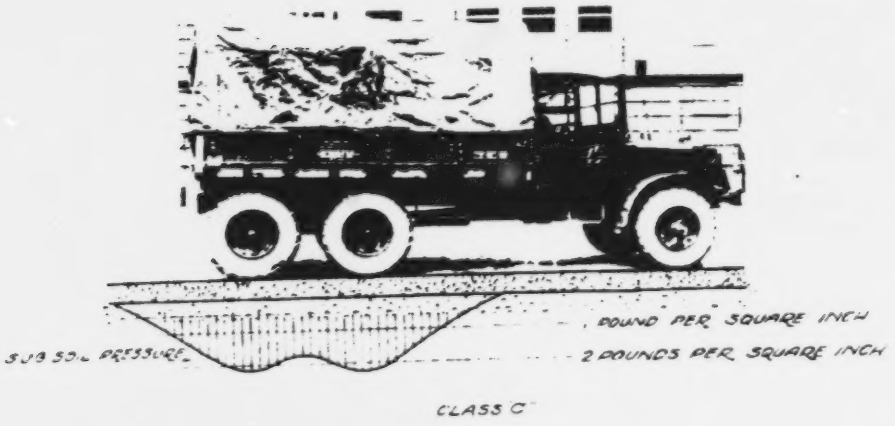


Figure A2a Road Loading - 6 Wheel

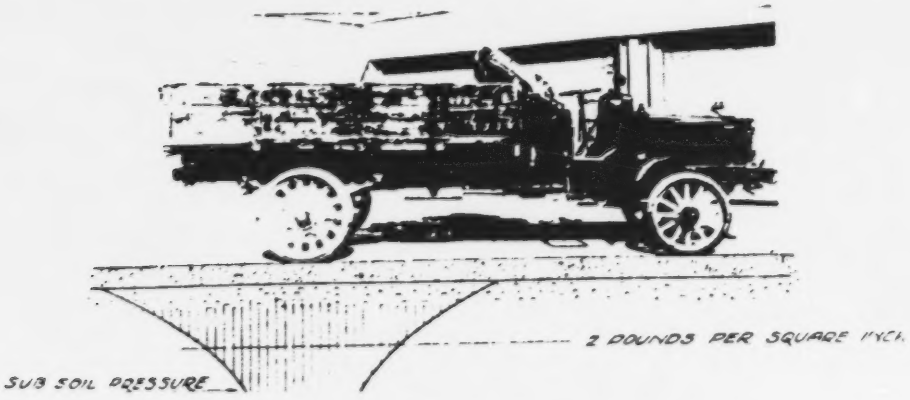


Figure A2b Road Loading, 4 Wheel

STEEL SPRINGS AND WALKING BEAMS

3. THE FREIGHTLINER FOUR-SPRING EQUALIZER SUSPENSION

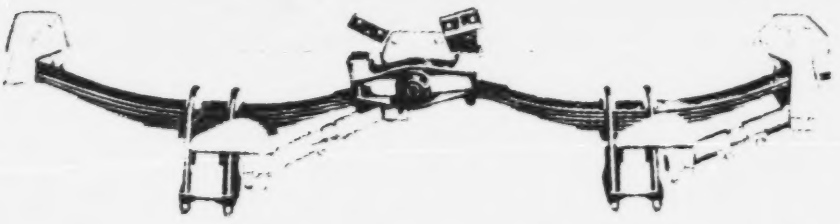
Norman B. Chew, SAE # 650628

ABSTRACT

Spring tandem suspensions fall into three basic categories with reference to their attachment to the frame.

Freightliner suspension is the three-point, four-spring type. This type has definite advantages in drive line articulation and has a further advantage in frame loadings. This paper points out the importance of suspension articulation with reference to drive line spline slip rather than the more common attention given to drive line angle parallelism. It further deals with the loads imparted into the frame by the suspension and deals specifically with the Freightliner three-point suspension. (Figure A-3)

The Freightliner three-point suspension provides good drive line slip control, good frame load distribution, and simplicity of installation, along with light weight, good ride, and versatility. The weight savings using some magnesium components are specified.



Slip end springs - Four torque rods, two of which are adjustable.

Figure A-3 Freightline 3-Point Suspension

STEEL SPRINGS AND WALKING BEAMS

4. DESIGN AND APPLICATION OF TRI-DRIVE TRUCKS

A.N. Schuppert, SAE # 650725

ABSTRACT

The tri-drive vehicle was developed to fill a specific need by operators (primarily construction operators), to allow them to take advantage of increased maximum gross vehicle weights permissible in several states. In order to take advantage of these increased legal weights and furnish adequate vehicle capacity and mobility, new components and new application standards were developed. This paper describes the problems encountered and what was done to solve them.

The tri-drive vehicle fulfills the design objectives very well, as evidenced by:

1. Increased legal payload
2. An equal 1/3-1/3-1/3 weight distribution to each of the three rear axles.
3. Excellent off-highway maneuverability as a result of all three axles driving and a suspension that allows a full 8 in. of vertical axle articulation.

5. TAPERED MULTILEAF SPRINGS LIGHTEN A TANDEM SUSPENSION

Ira Maxon, SAE # 680119

ABSTRACT

This paper deals with a new 38,000 lb. capacity truck tandem suspension of light weight. Four taper-leaf springs, each assembly consisting of two leaves, are arranged to provide a two-stage spring action. Equalization of load between axles is obtained through a long equalizer pivoted at the center. Load is distributed along the truck frame at six mounting points. Acceleration and braking forces are transmitted through torque eye leaves. Rubber bushings eliminate the need for lubrication at the pivot points. (Figure A-4, next page)

The design goals of preserving good laden riding qualities, improving unladen riding qualities, substantially reducing weight, insuring durability, providing good wind-up control, and preserving the "new-Truck" ride during the

(Cont'd) 5. life of the springs, have all been accomplished. These goals were achieved by utilizing many already proven components, the use of tapered two-leaf springs, low spring stresses, and minimal interleaf friction.

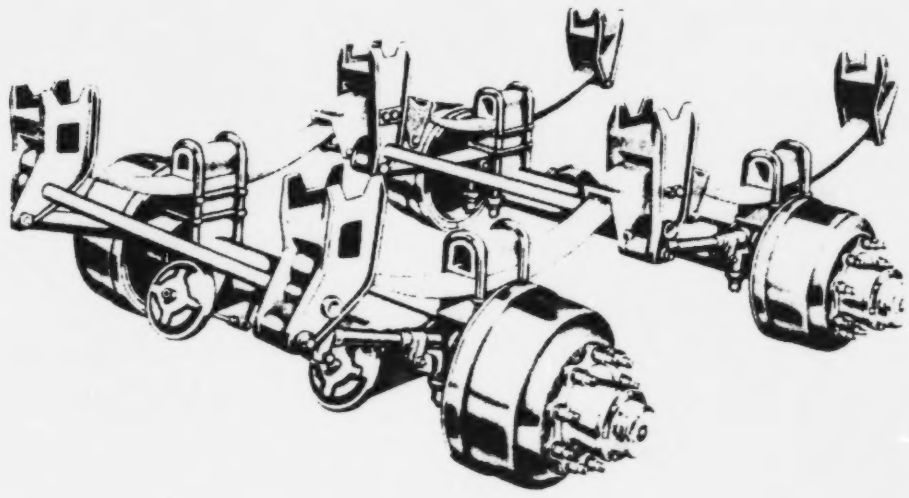


Figure A-4 Three-point taper-leaf steel spring suspension

6. HEAVY DUTY TRUCK TANDEM SUSPENSION FOR ON/OFF HIGHWAY APPLICATIONS

Thomas H. Watson, SAE # 740306

ABSTRACT

This paper describes the design, development, and testing of a heavy duty truck tandem suspension intended for vehicles that must operate both on and off the highway.

The notable features of this suspension are a nonlinear spring rate, improved axle vertical travel, the wide span over which the suspension is mounted to the frame, and the ease with which the suspension accommodates different spacings between the tandem axles.

It uses 4 point support, cantilever springs, cams for nonlinear rate, high roll centre - recommended for mixers.

(Cont'd) 6. The suspension was designed specifically for the on-off highway vehicle. It was designed to do a specific job well, and is not being marketed for applications such as over-the-road use, to which it is not ideally suited. Problems previously seen on on-off highway suspensions that have been solved with this suspension are the "mixer lean" problem, excessive frame rail deflection requiring use of frame liners, inadequate roll stability, and rough ride when empty.

Rough ride problems were eliminated using an extremely nonlinear spring rate. The roll stability was enhanced by the spring rate characteristics, and by providing a high roll center to decrease load side shifting. The mixer lean and frame rail deflection problems were reduced by spreading out the support points at which the suspension attaches to the frame rail.

7. A CONSTRUCTION TRUCK FRONT TANDEM SUSPENSION WITH ONE DRIVING AXLE

Robert W. Stieg, SAE # 760253

ABSTRACT

This paper describes the design requirements and solutions for a heavy-duty tandem steering axle suspension, and the related special 8 x 4 construction truck chassis. By restricting the tandem axle load equalization to the maximum legal load range only, it was possible to design a suspension using individual axle mountings. This mounting achieved substantial benefits in weight, performance, cost, and development time over an equalizing beam type suspension as applied to a vehicle front end. In addition, the design incorporates a variable front axle load distribution feature which increases empty vehicle and off-highway mobility by allowing a temporary biasing of weight to the front driving axle. Consequently, the concept is particularly well suited to a front tandem with only one axle driving. Also described are experimental automatic control variations, unsuccessful and otherwise, that led to the final development.

Front tandem installations in trucks have tended to be heavy, expensive, and very specialized departures from

(Cont'd) 7. high production practice. It was found that by restricting the axle load equalization to the maximum legal loading, an independent axle mounting design then became feasible. On a dumper-mixer truck, this design proved highly advantageous for a front tandem installation over an equalizing beam type suspension used in this position. Development work was conducted on several systems of automatic air spring control using an air leveling valve; however, to eliminate the problems of winter environment and rugged off-highway operation, a cab mounted driver-controlled valve was finally adopted for reliability. The air spring adjustment maximizes traction for the empty vehicle, equalizes axle loading for the loaded vehicle, and also provides the added mobility feature of an automatic weight transfer to the driving front axle when locking the inter-axle differentials. The concept, is therefore, particularly well suited to a front tandem with only one axle driving

8. HEAVY DUTY-TRUCK SUSPENSIONS

F.R. Sternberg, SAE # 760369

ABSTRACT

Truck suspensions for heavy-duty trucks perform complex and conflicting functions and have been the subject of much development. This paper provides information on many types of suspensions presently in use and indicates those applications for which the particular types of suspension in use are best suited. While primary emphasis is placed on leaf spring suspensions, data are also provided on other types of suspension such as rubber, air, torsion bar, and solid mount suspensions which are in current use.

The paper is very comprehensive, giving in-depth appreciation of the many types of tandem suspensions, with insight into the basic requirements and functions of suspensions, stress levels, and deflections.

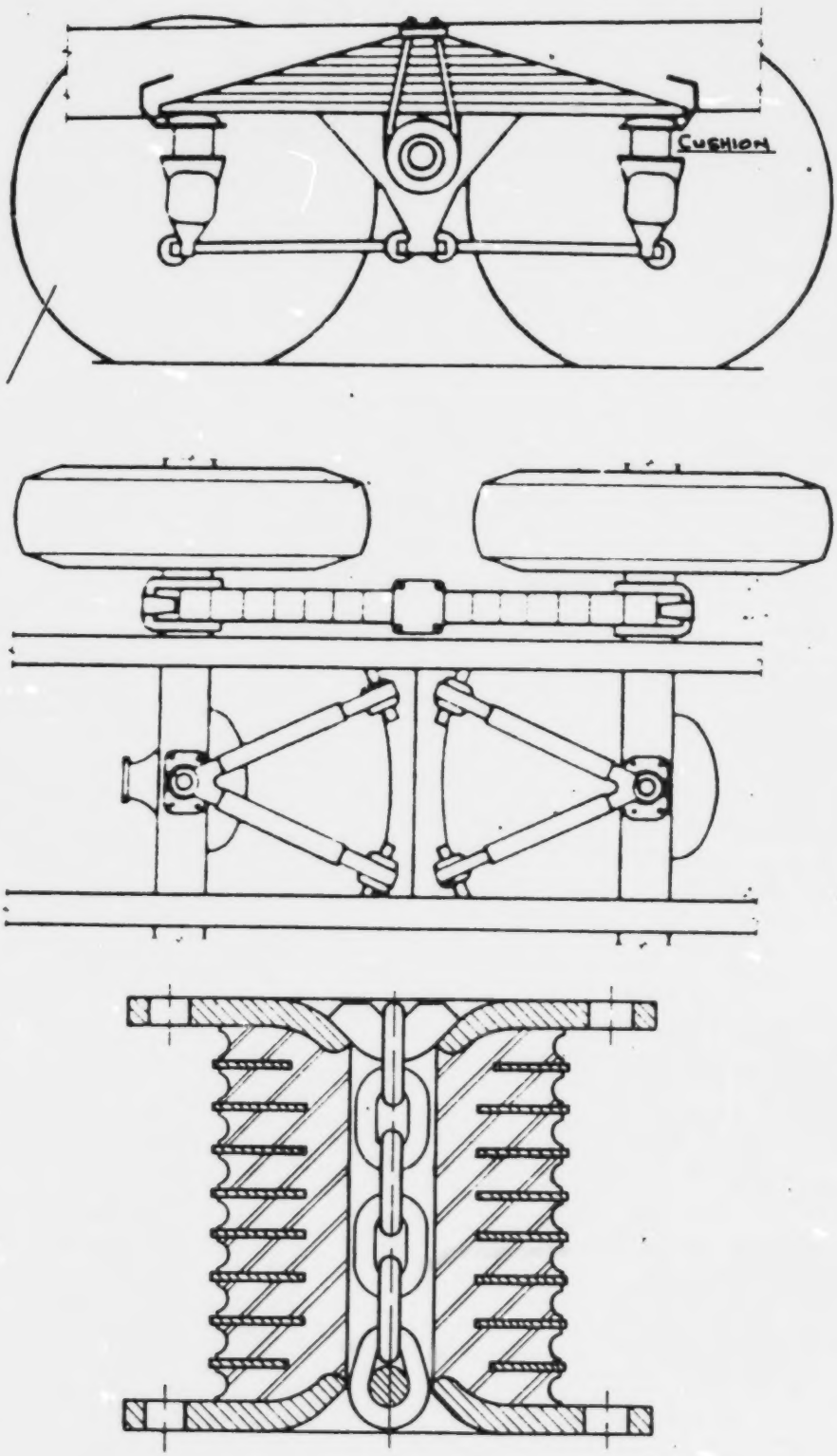


Figure A-5 Rubber Cushion, used with steel semi-elliptic springs (Volvo)

FRP AND CARBON FIBRE SPRINGS

9. INFLUENCE OF RESILIENCE ON ENDURANCE IN A TANDEM AXLE SYSTEM

Gosta E. Vallin and Lars-Goran Larsson, SAE # 800526

ABSTRACT

A thorough study of the forces in the suspension components of a new tandem axle concept revealed very high parasitic forces due to friction. By reduction of friction and by adding some resilience the forces were considerably reduced giving longer life and extended load carrying capacity to the system. The way this was achieved is shown in this paper. (Figure 5-A)

10. LIGHT TRUCK FRP LEAF SPRING DEVELOPMENT

Terry N. Trebilcock and Joseph N. Epel, SAE # 810325

ABSTRACT

The Budd Company designed, prototyped, and laboratory/field tested a fibreglass leaf spring for a Ford Econoline Van. (Figure A-6)

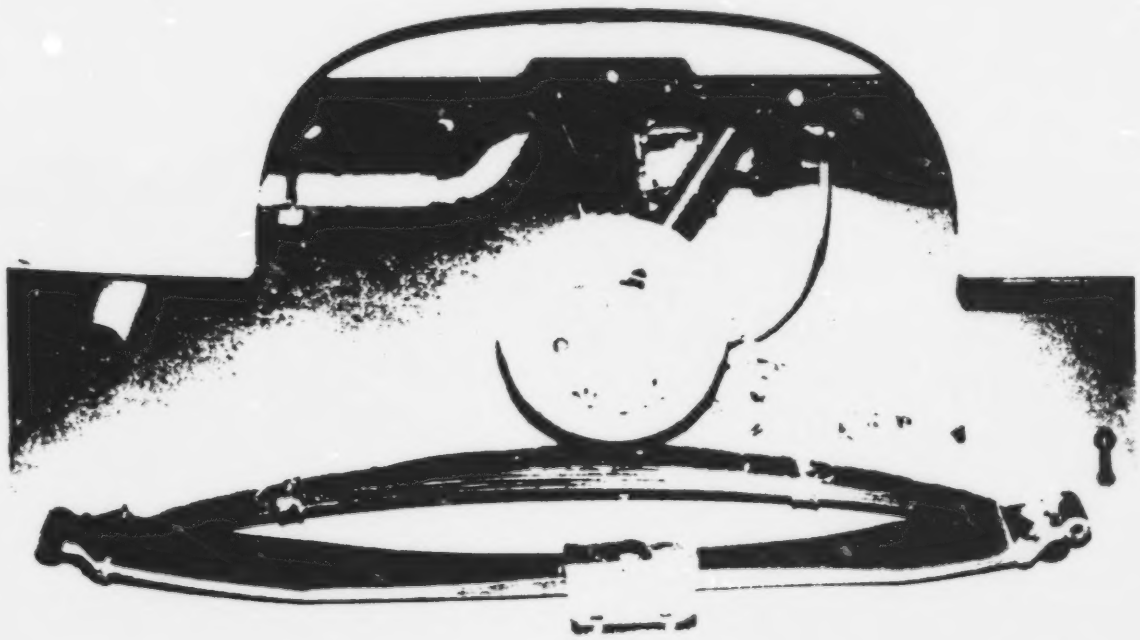


Figure A-6. FRP Econoline Van Spring, Dismounted, is in foreground.

(Cont'd) 10. Prior to design and materials selection, extensive development work was conducted on fiber/resin systems. Computer design programs were written which would accept conventional leaf spring parameters and output nominal stresses, tooling data, and weights for a selection of unidirectional monoleaf configurations. Extensive prototype testing was conducted on a laboratory leaf spring fatigue tester equipped with a simultaneous brake torque simulator (for attachment testing). Field testing was conducted on urban roads and at Ford and G.M. Proving Grounds to correlate materials, design, and laboratory-field data.

The information presented by this paper clearly points out the feasibility and potential of fiberglass leaf springs. An epoxy resin system which can sustain elevated temperature has good fatigue resistance, and relatively good creep resistance has been developed.

Stresses due to secondary loads in this design, such as torsion and side thrust, are no problem; and field tests showed that laboratory tests are more severe than test track conditions.

Molding processes which yield parts relatively void free are possible, enabling better static and dynamic reliability.

A proprietary fastening system is available by which dynamic loads can be transferred from the road to the spring without causing premature failures.

Although there are many design questions answered by this paper, there are still many open issues that need to be answered such as: How light can the attachments be made and still remain effective? Although short-term creep is no problem, what about long-term creep over several years? What is the best means of quality control? How long can the press cure time be reduced while maintaining part integrity? And so on.

These and other similar questions will need to be answered before any design can be 100 percent structurally and cost effective. They are the objective of future studies.

11. HYBRID GRAPHITE FIBER COMPOSITES FOR THE AUTOMOTIVE INDUSTRY

S.L. Cross, SAE # 791037

ABSTRACT

This paper summarizes the status of hybrid graphite fiber composites as related to the automotive industry. Included are: (1) basic raw material forms available for use in hybrid construction, (2) relative tensile properties of unidirectional composites as compared with hybrid forms being developed, (3) some example applications, with emphasis on raw materials and construction, and (4) projected economics for the potential use of hybrid materials. Over the past several years, raw material suppliers have concentrated on developing material forms suitable for high-volume manufacture of automotive parts. Emphasis has been on the more economical hybrid construction. In general, hybrid graphite construction includes between 5 and 25% graphite reinforcement, with the balance being fiberglass and resin. Future economics based on projected escalation curves look favorable for hybrid graphite composites as a result of anticipated reduced fiber prices.

Hybrid graphite fiber construction is currently viewed as a final approach to maximum weight reduction. However, as the issues are resolved and better understanding and higher confidence in its use is achieved, wider acceptance is anticipated. Continued development and refinements in the raw material forms will lead to more efficient and economical introduction into currently used fiber-reinforced molding materials. More complete characterizations of the properties and processibility of these hybrid materials will provide better options for the material selection. Basic data available today have shown the potential for improved structural characteristics. Further studies are required to fully assess the economic potential. Automotive industry interest and support are vital to the success of this new material. Until this support develops, the acceptance and increasing use by aerospace, industrial, and leisure industries will ensure continuing growth and raw material price reductions. However, the automotive industry clearly represents the greatest potential for high-volume consumption and, therefore, the greatest driving force for achieving the necessary low-cost material.

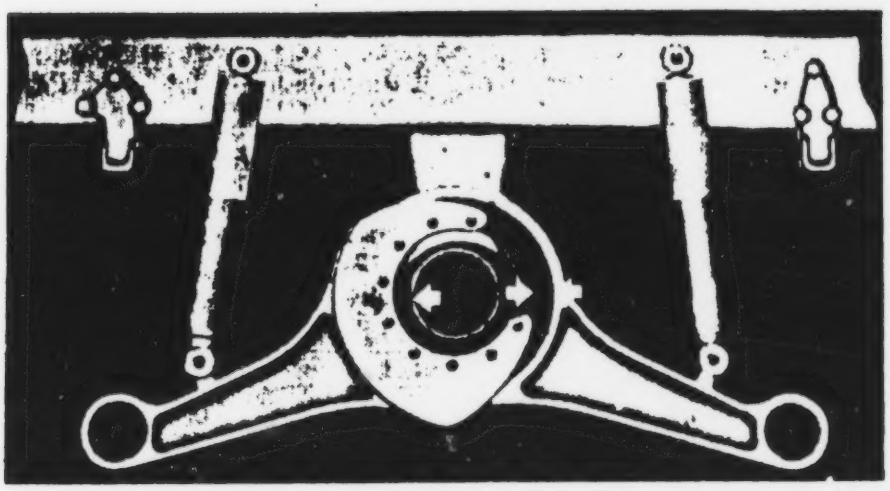


Figure A7a Free Position, rubber torsilastic suspension

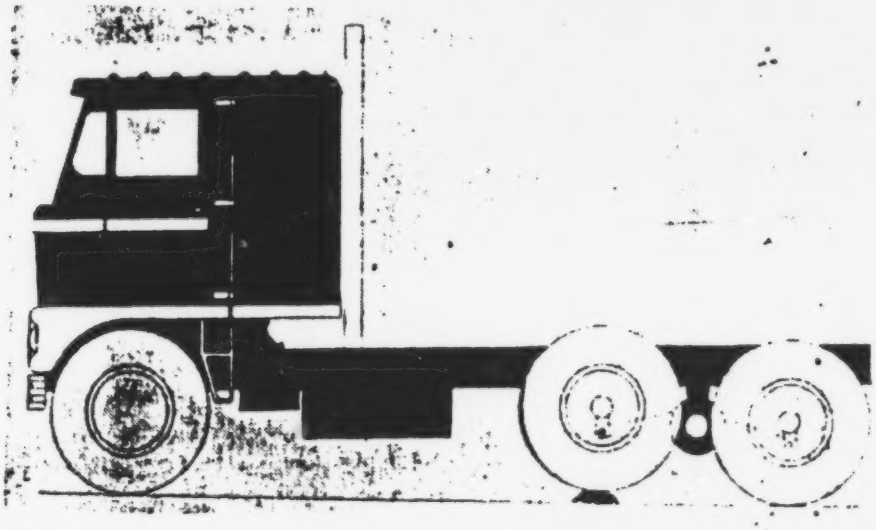


Figure A7b Articulation, torsilastic rubber suspension

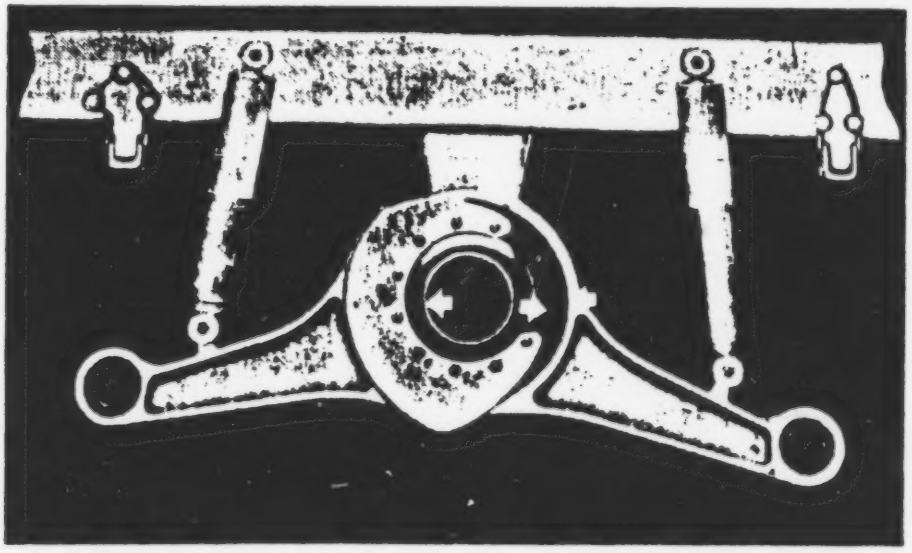


Figure A7c Detail, torsilastic rubber suspension

ELASTOMERIC SPRINGS

12. A NEW "TORSILASTIC" RUBBER TANDEM SUSPENSION

Walter L. Luli and Warren J. Young, SAE # 660142

ABSTRACT

A concept of an entirely new single point tandem axle suspension designed only for highway operation, featuring a torsion rubber spring, independent wheel action, high spring deflection, controlled axle movement, and maximum arm articulation is presented. A superior ride, easier steering, reduced tire wear, weight reduction, ease of maintenance, elimination of friction, no lubrication required, and a balanced driveline under all load conditions are featured. NOTE: This is not a walking beam design of a suspension.

This paper attempts to give as broad a picture as possible of the design, development, testing and operational features of the suspension. (Figures A-7a and A-7b)

The advantages of this suspension over conventional type suspensions are:

1. Improved ride.
2. Lower stressed - longer life.
3. Easier steering.
4. Reduced tire wear.
5. Light weight.
6. Reduced maintenance.

Improved Ride - Various factors point to proof why the high deflection suspension has a superior ride than the low deflection suspension. The periodicity-suspension natural frequency versus deflection data show the periodicity to be approximately 115 as compared to conventional suspensions which average approximately 200 cpm.

The examination or ride comparison between Suspension A, "Velvet-Ride", and Suspension B indicat s marked superiority of the "Velvet-Ride". While acknowledging that the present art of ride evaluation with today's instrumentation leaves a lot to be desired, it's chosen to present the picture in terms of "g" forces and compare by percentages of one suspension to another.

Lower Stressed - Longer Life - The low stress (tensile 240 psi, shear at ID 108 psi, and shear at OD 68 psi) insures long life. These values are less than 30% of present day

(Con't) 12 similar applications on bus suspensions. There are no wearing parts and all castings, although safely designed, have the protection of the rubber both at the spring and axle ends to provide a cushion against sudden shock from the road.

Easier Steering and Reduced Tire Wear - The theories explained in the section "Design and Test" point out how the "Velvet-Ride" design reduces the steering effect caused by the tandem rear axles, as compared with the well established fact that conventional spring suspension on most tandem axles tend to resist or overrule the steering of the front axle. There should be little doubt that when the steering geometry of the system is improved, steering effort, turning radius, and tire wear from scuffing are also reduced.

Field reports from trucking firms confirm that the "Velvet-Ride" provides superior steering control and longer tire life.

Light Weight - The complete "Velvet-Ride" suspension, when compared with conventional suspensions, weighs as much as 305 lb less, providing a sizable weight advantage.

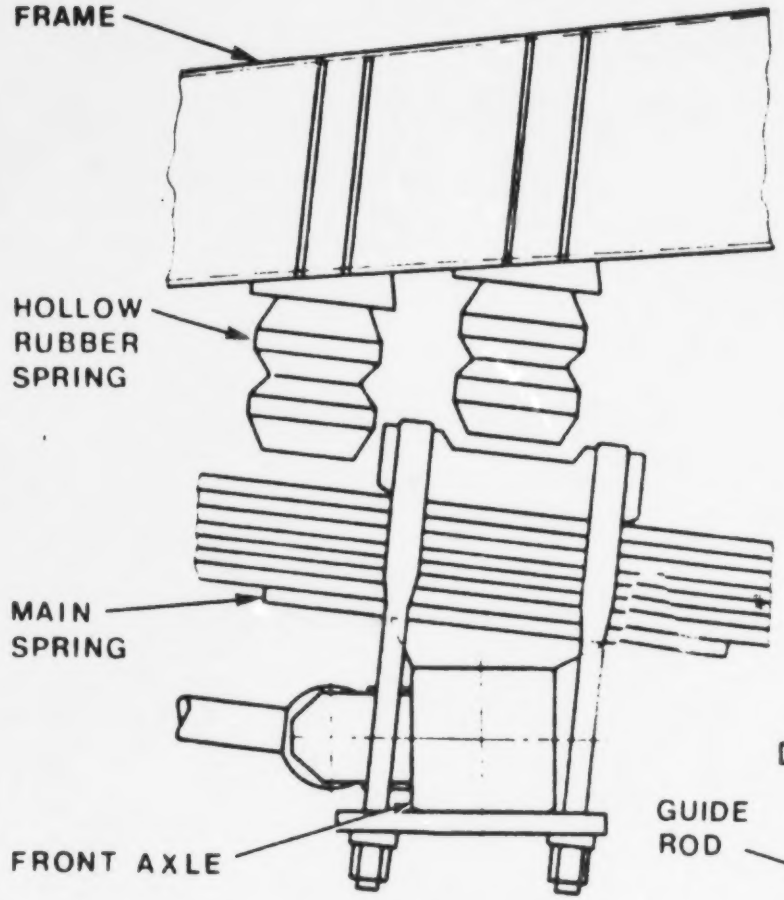
Reduced Maintenance - No points to lubricate or adjust. Friction completely eliminated, therefore, no wear. Replacement of any member or assembly can be easily made and either "A" or "B" springs can be removed and replaced without the loss of the suspension arms. Since the turning radius geometry is improved over conventional suspension resulting in reduced wheel scuff, the stresses on associated parts are considerably reduced.

13. HOLLOW RUBBER SPRINGS FOR PROGRESSIVE RATE SUSPENSION

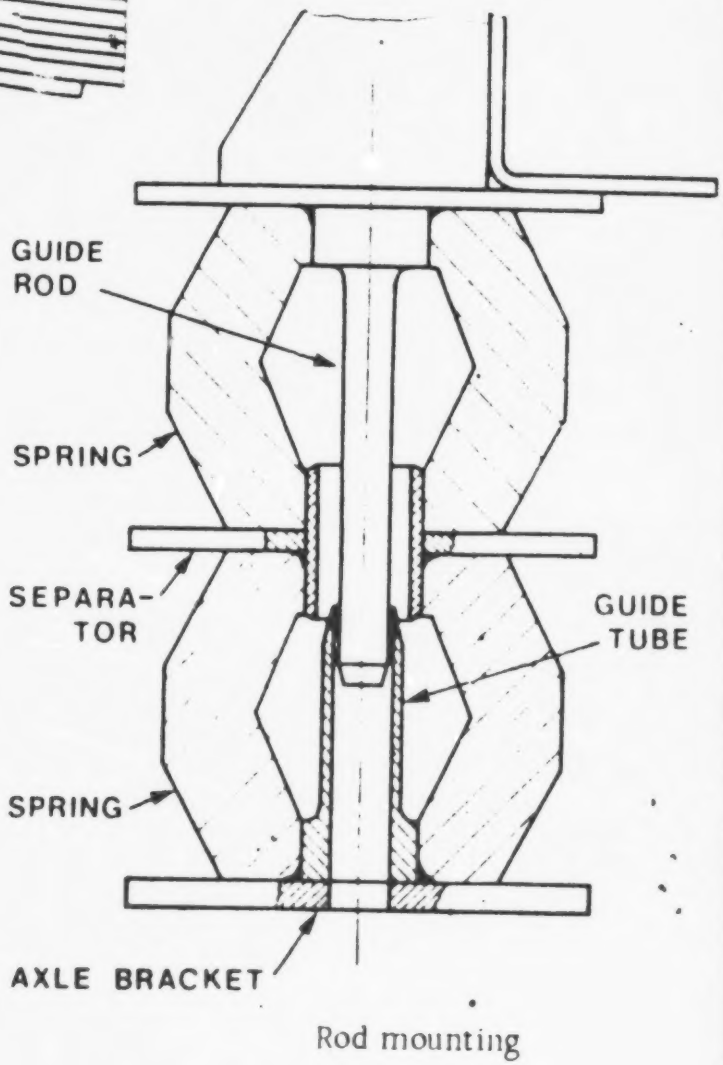
H. Viereck, SAE # 690097

ABSTRACT

This paper describes a series of rubber compression springs that obtain large deflections and progressive rates from a special configuration. Functioning of the basic spring is explained. Factors influencing the performance and service life are discussed. Examples of progressive rate suspensions using hollow rubber springs singly and in combination with other spring media are presented. (Figure A-8)



Front suspension



Rod mounting

Figure A-8 Hollow rubber springs for progressive rate

(Cont'd) 13. With properly selected and installed hollow rubber springs, progressive rate suspension systems can now be designed for a wide range of vehicles. These systems are simple, have high capacity per unit weight, sustain substantial overloads without bottoming under shock loads and reduce forces transferred to chassis.

14. ELASTOMERIC SUSPENSIONS WITH GEOMETRIC SPRING RATES FOR OFF-HIGHWAY VEHICLES

James E. McClelland, SAE # 700738

ABSTRACT

This paper describes an off-highway vehicle suspension using modular elastomer-bonded-to-metal impact cushioning pads. The modular impact pads are stacked inside telescoping struts which are connected between the axle and the frame. The rheology of the elastomer, and the cross-sectional shape of the pads give a geometric load vs. deflection curve; a near-linear spring rate vs. load curve, and a near-constant frequency at any level of load. These characteristics limit excessive deflections and increase the stability and controllability of the vehicle. The modular impact pads are self-damping; dissipating a large percentage of the applied energy, and require no auxiliary shock absorbers. A wide range of spring functions and damping functions are possible by utilizing different elastomers, pad shape, pad sizes, and numbers of pads. Initial cost and weight are less than conventional springs and struts. Maintenance costs are negligible and service lives of more than 25,000 operating hours have been recorded between overhauls. (Figure A-9)

The suspensions described in this paper feature:

1) A Geometric Spring Rate which provides:

   a) A comfortable ride empty or loaded.
   b) Stability at all vehicle weights.
   c) Near constant bounce frequency at all vehicle weights.

2) A modular System adapting itself to:

   a) A wide range of vehicle sizes and weights.
   b) A wide range of spring functions.

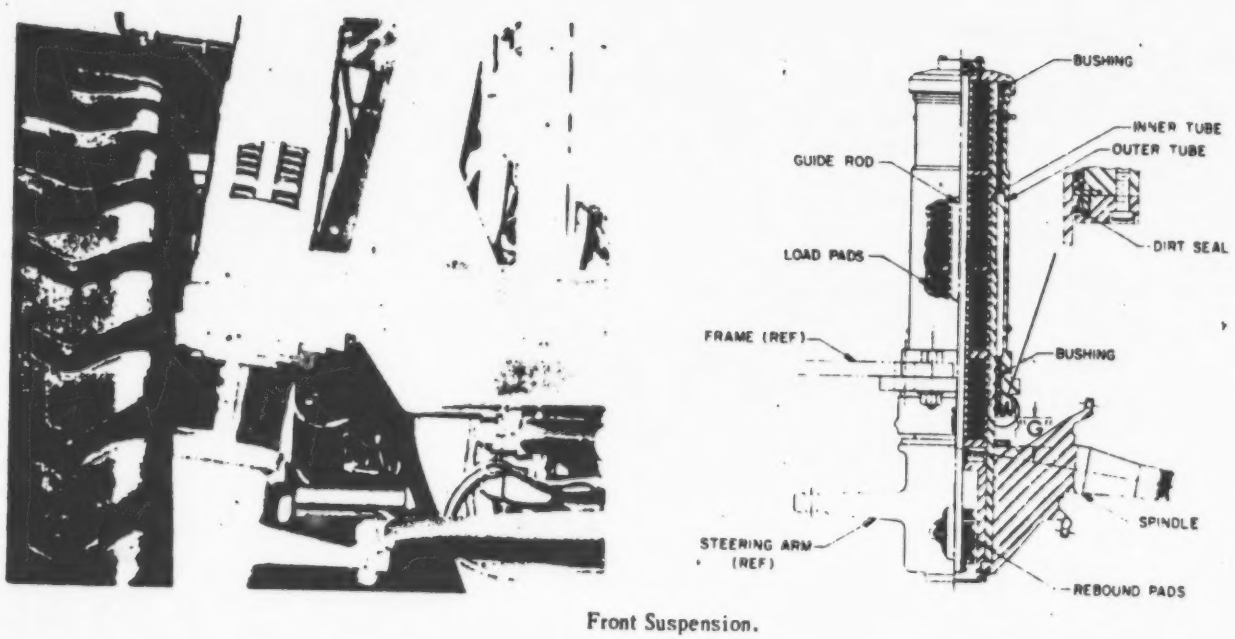


Figure A-9 Heavy mining truck suspension, using rubber discs in compression

(Cont'd) 14. 3) A Self-Damping ability which:

a) Dissipates over 50% of the applied energy.
b) Quickly damps out vehicle motion.
c) Eliminates auxiliary shock absorbers.

4) Energy Storage Capacity which, per pound of spring material is:

a) 2100 times that of a steel leaf spring.
b) 1400 times that of a steel torsion coil spring.
c) 20 times that of an orthogonal elastomer block.

5) Low cost, including:

a) Low initial cost.
b) Low operating cost.
c) Minimal maintenance expense.

6) Service life in excess of 20,000 operating hours.

7) A background of over 140,000,000 suspension operating hours of trouble-free service.

15. A NEW ELASTOMERIC SUSPENSION SPRING

Regis V. Schmitt and Matthew L. Kerr, SAE # 710058

ABSTRACT

This paper describes a constant natural frequency spherical elastomeric spring element. The concept of constant natural frequency and its advantage in providing consistent ride quality with varying vehicle weight is reviewed.

Performance data on the spherical spring for both laboratory and field tests is presented and evaluated.

This paper examines the principle of using a constant frequency spring for consistent control of transmitted road disturbance with varying vehicle loads. The spherical elastomeric spring is shown to have constant frequency characteristics in a part which has been applied to a vehicle suspension. Field evaluations have shown that the spherical spring system provides a stable and consistent ride for an empty and loaded vehicle.

ELASTOMERIC SPRINGS

16. A NEW CONCEPT IN COMMERCIAL VEHICLE SUSPENSION

Wallace G. Chalmers, SAE # 730654

ABSTRACT

Developed to cut down on maintenance costs and increase the earning power of the vehicle, this family of suspensions provides for improved vehicular behavior - items such as stability, braking, cornering, and overall ride. The suspensions utilize a principle of providing a cushioned variable rate ride through the use of molded rubber springs. Floating walking beams distribute weight equally on both axles in the case of tandems. The axles are positively located by upper wishbones and lower torque rods. The parallelogram thus formed prevents windup and axle hop. The correct use of metals shows a substantial weight saving in the entire model range. (Figure A-10a and A-10b)

The suspensions for commercial vehicles as described in this paper appear to offer good perforamce characteristics, including ride and handling, whether on-highway or off-highway, empty or laden. The features of the springs and the axle linkage have been exploited and the results have matched the original objectives.

While the basic concept of the suspension and the design of components were based on sound engineering principles, their refinement to their present standards is the result of extensive field tests and on-the-job experience.

17. ADD AN AXLE BY THE USE OF AN EQUALIZING AIR SUSPENSION

Lloyd D. Masser, SAE # 650726

ABSTRACT

Independent equalizing air suspensions are being added to trucks, tractors, and trailers in order to increase their capacity. That is, independent air suspensions are being combined with standard production suspensions so as to economically produce vehicles with greater versatility. Axle load equalization is obtained by regulating air pressure to the air suspension, which controls the load on the independent axle.

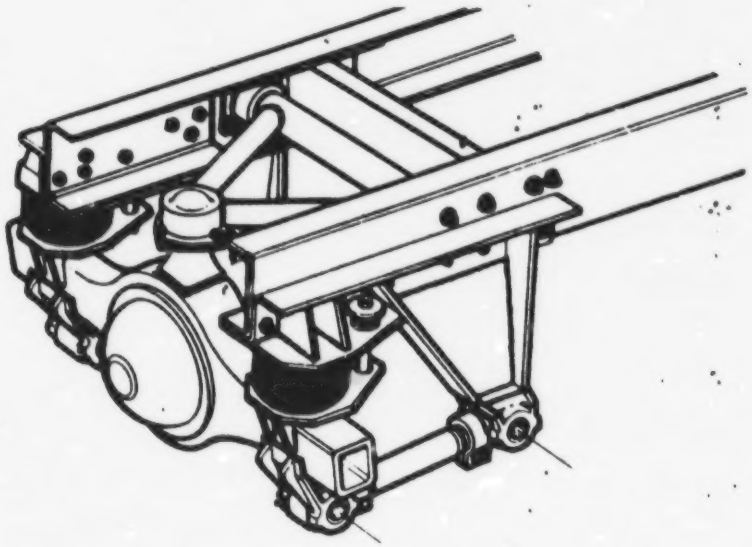


Figure A10a Rubber single axle truck suspension(Chalmers)

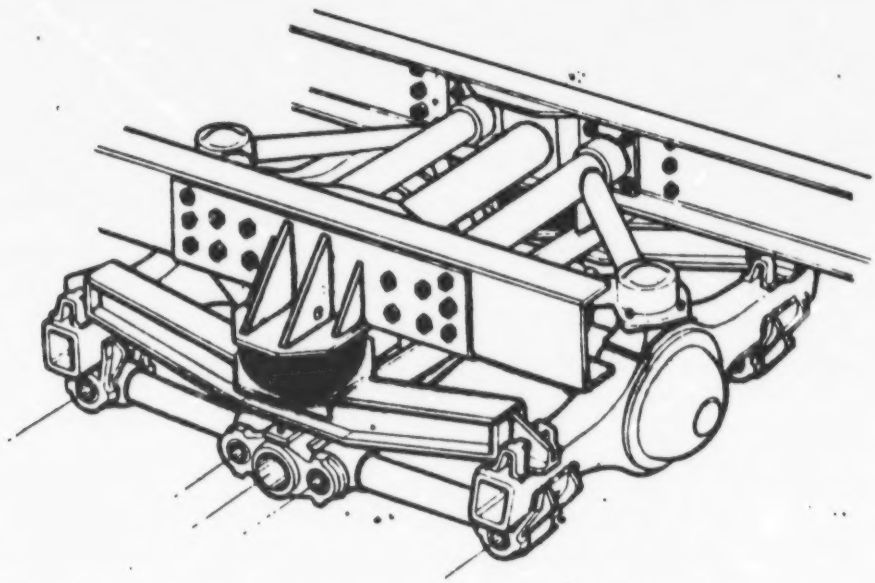


Figure A10b Rubber truck tandem suspension (Chalmers)

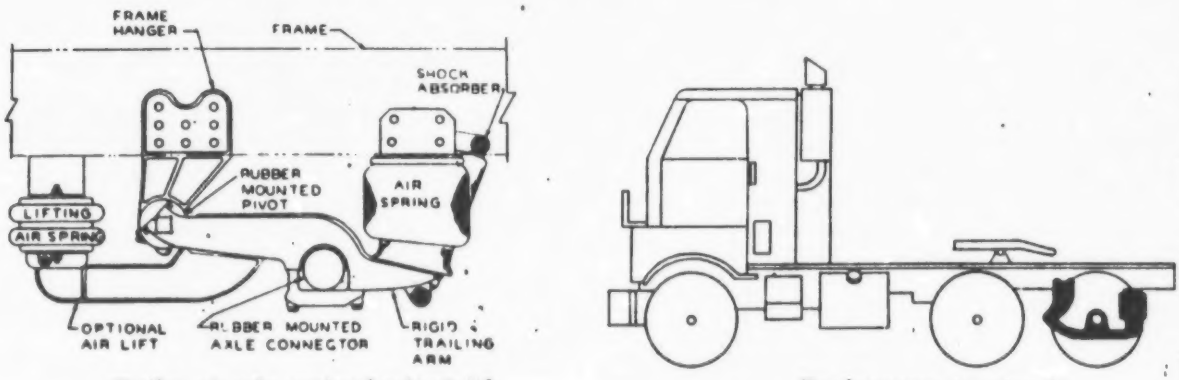


Figure A-11 Truck Equalizing Air Suspension

(Cont'd) 17. This paper describes the design and application of the independent equalizing air suspension as used by the trucking industry. (Figure A-11)

It would be ideal for the transportation industry if all the operating conditions such as roads, terrain, state regulations, and loads were the same. If this were the case, a few standard models would meet all transportation requirements.

However, this is obviously not the case. Therefore, original equipment manufacturers must have the capability to modify economically the standard model designs, to meet the demand for specialized equipment. Also, operators must be able to modify existing equipment when laws and/or operating conditions change.

As discussed in this paper, the independent air suspension can be readily placed at any desired location on a wide variety of vehicles. For this reason, the addition of an independent equalizing air suspension has proved to be the most flexible and economical method, for both the original equipment manufacturer and the operator, of customizing standard models to solve the many different operating problems in a rapidly changing industry.

18. DESIGN, APPLICATION, AND COMPARATIVE TESTS OF TRAILER AIR SUSPENSION SYSTEM

O. Lee Henry, SAE # 660141

ABSTRACT

Air suspension systems for highway trailers offer changes in ride characteristics which affect cargo transport, driver comfort, and structural design. These changes have brought about new considerations for those responsible for designing and maintaining highway vehicles, as well as for those concerned with the effects of shock and vibration upon both cargo and operator.

The purpose of this paper is to describe the design principles of Neway Equipment Company's trailer air suspension, to illustrate certain applications of this suspension system, and to present results of comparative ride tests. (Figure A-12)

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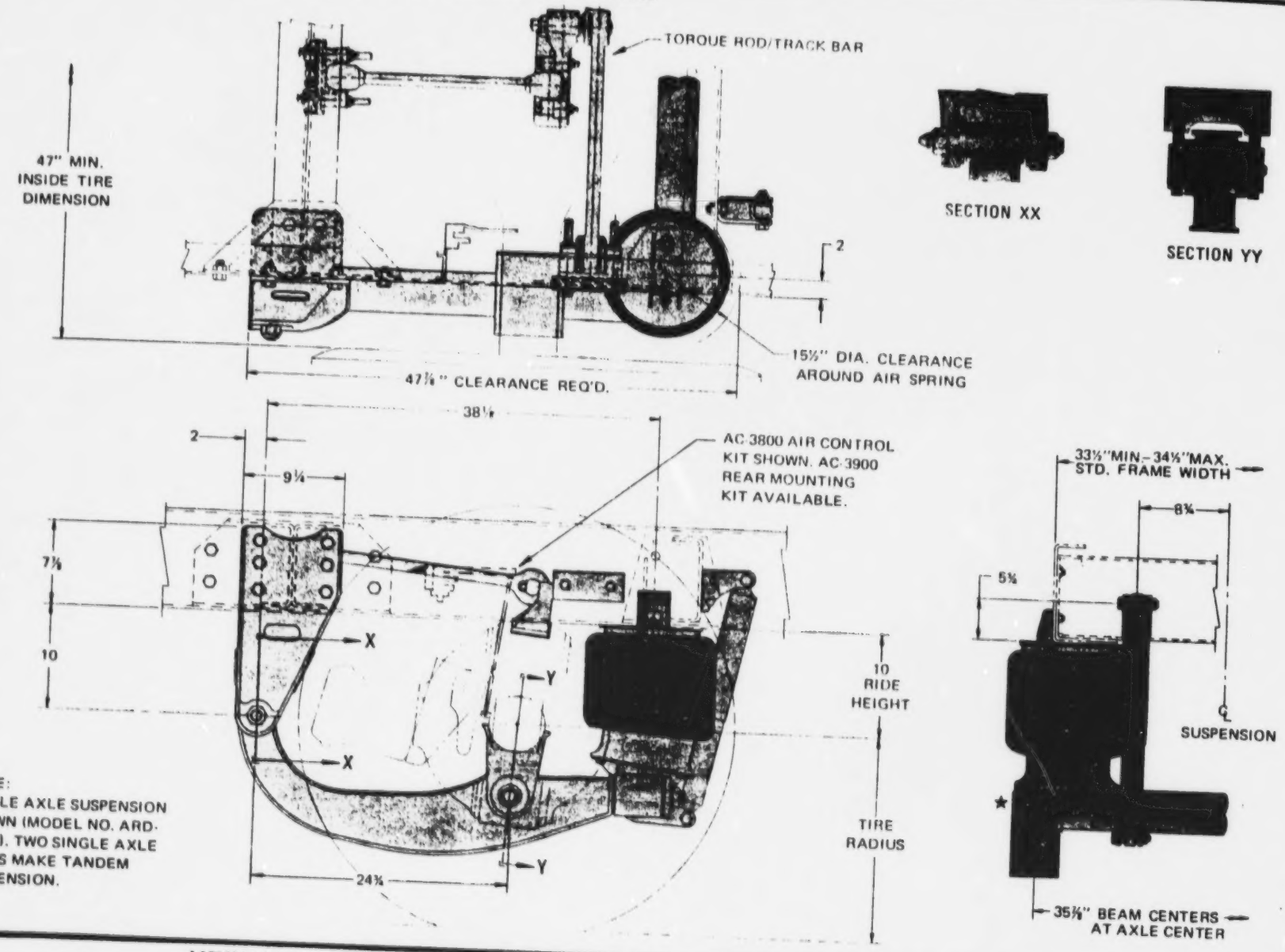


NOTE:
SINGLE AXLE SUSPENSION SHOWN (MODEL NO. ARD-125-6). TWO SINGLE AXLE UNITS MAKE TANDEM SUSPENSION.

Figure A-12

(Cont'd) 18. The test program proved to be an effective way of demonstrating some of the advantages of air suspension. This is primarily because the air suspension was sufficiently different from the leaf springs that results were evident with relatively simple data analysis techniques. Therefore, the test program satisfied the primary objective. However, when analyzing the data and attempting to understand the effect of suspension characteristics on vehicle dynamics, several limitations of road testing became evident. These are:

1. Road testing becomes expensive if many variables are to be evaluated.

2. Complete knowledge of (and control over) the input functions is difficult.

3. It is difficult to detect minor changes in components.

4. The system is nonlinear and therefore results cannot be generalized.

5. It is impossible to isolate parameters, such as viscous damping, coulomb friction, spring rate, and others.

Based upon the above objections to road testing, it is suggested that analog simulation, combined with component testing to supply input information, is an excellent method to develop an understanding of the whole field of vehicle dynamics. Once accurate models have been developed suspensions can be modified--first on the analog simulator, then in hardware--to meet specific transmissibility requirements. The trailing arm air suspension fits nicely into the analog approach since the functions of the suspension, such as damping and spring rate, are performed by separate components to a large extent. Thus, once a certain component characteristic is found to be desirable from analog simulation, the air suspension can be relatively easily modified.

AIR SUSPENSIONS

19. IH AIR SUSPENSION

W.S. Locks, SAE # 700869

ABSTRACT

A new truck air suspension system has been developed which provides excellent roll stability and articulation capability without compromising the exceptionally soft ride characteristics of air suspension. The concurrent realization of roll stability and articulation capability for tandem driving axles has been achieved by designing nearly rigid, roll resisting, rear axle, to be used in conjunction with a freely articulating, forward rear axle. This principle applies equally well for single driving axle vehicles, where the rigid axle provides the same roll stability while articulation, not really a problem on single axle vehicles, is provided by frame and front axle suspension flexibility.

The new air suspension developed for single and tandem axle trucks offers excellent ride, exceptional roll stability, and articulation capability. This performance has been achieved by the unique design of the tandem suspension which allows the forward axle to articulate freely while the rear axle imparts roll rigidity.

The new suspension has been fully integrated into a vehicle line with each chassis model engineered to be compatible with the suspension. The coordination of axle design and thorough suspension engineering have resulted in a light-weight suspension which has been qualified by extensive testing for performance and durability.

20. DEVELOPMENT OF AIR SUSPENSION SYSTEMS FOR HIGHWAY TRACTOR AND TRAILERS

O. Lee Henry, SAE # 700893

ABSTRACT

Trailer air suspensions have been commonly applied to many segments of the highway transportation industry, since one or more of the unique characteristics of air suspensions solve particular operating problems.

Recent developments in tractor drive axle air suspensions now permit application of the same basic

(Cont'd) 20. characteristics to power equipment. In addition, with air suspensions available for both trailer and tractor, many new concepts in vehicle design and material handling become practical.

The purpose of this paper is to generally review the characteristics of air suspensions, review the development of a drive-axle air suspension, and finally show how they are applied to over-the-highway heavy duty vehicles.

Practical air suspension hardware is available which offers many unique advantages. Cognizance of these characteristics allows the vehicle designer and transportation system planner to solve operating problems and improve operating efficiency.

21. AIR RIDE TRUCK SUSPENSION

A.D. McLean, SAE # 700894

ABSTRACT

Air spring suspensions have reached a point in their development where they are quite dependable. Their use in the rear of truck chassis is filling the need for the "better ride both ways" requirement of heavy duty Class 8 trucks. (Figure 1-13)

The general conclusion that can be arrived at when comparing the air ride truck suspension to others is that with a small additional know-how and maintenance of suspension air systems, the truck operator can have a chassis ride condition that is more nearly the same, both loaded and unloaded.

The inherent design of the air suspension height control system keeps the truck frames at the same height above the axles no matter what the load is.

The air springs can be used as scales by using accurate pressure gauges coordinated with scale house weights.

The current production air systems offer a real advantage to the operator.

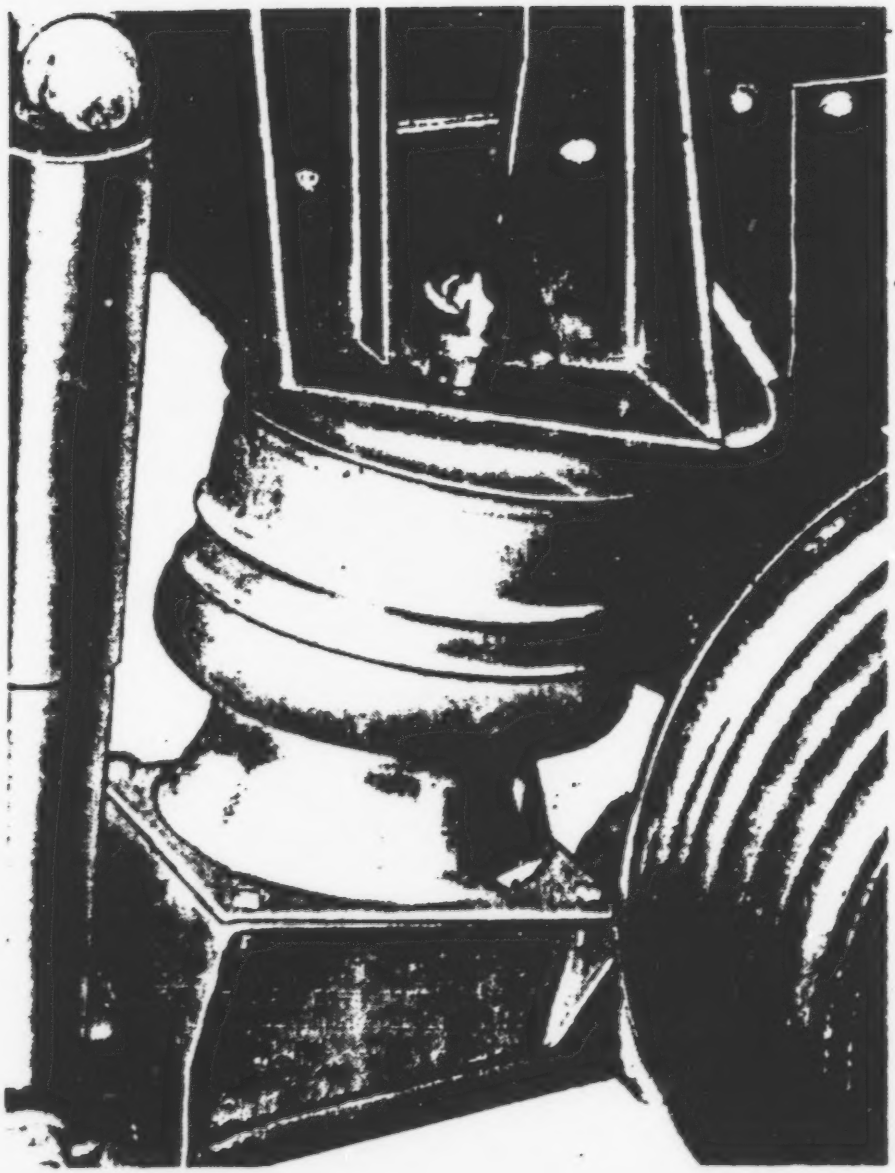


Figure A-13 Rolling lobe air springs

AIR SUSPENSIONS

22. EVOLUTION OF AN AIR SUSPENSION SYSTEM FOR TRUCKS

W.S. Locke, SAE # 720105

ABSTRACT

A new truck air suspension system has been developed which provides excellent roll stability and articulation capability without compromising the exceptionally soft ride characteristics of air suspension. The concurrent realization of roll stability achieved by designing a semirigid, roll-resisting, rear rear axle, to be used in conjunction with a freely articulating, forward rear axle. This principle applies equally well for single driving axle vehicles, where the rigid axle provides the same roll stability and articulation, not really a problem on single axle vehicles, is provided by frame and front axle suspension flexibility.

The new suspension was designed to fit vehicle models ranging 23,000 - 54,000 lb. gvw, and a saddle arrangement was developed to attach the rear axle housing to the trailing arm. Aluminum forgings were used in an effort to achieve minimum weight in every suspension part and all chassis components.

The high-quality ride offered by this new air suspension provides excellent chassis durability under all operating conditions for both single and tandem-axle trucks. The unique design, which imparts roll rigidity to the rear suspension without penalty to articulation capability, gives unprecedented stability for soft ride vehicles.

The new suspension has been fully integrated into the vehicle line, with each chassis model engineered to be compatible with the suspension. The coordination of chassis design and thorough suspension engineering has resulted in a light-weight suspension that has been qualified for performance and durability by extensive testing and verified by several million miles of service.

AIR SUSPENSIONS

23. GMC ASTRO AIRE REAR SUSPENSION

Robert F. Schmidt, SAE # 720106

ABSTRACT

The purpose of this paper is to describe the development by GMC, of an over-the-highway 34,000# tandem rear axle air suspension system for heavy duty truck/tractor applications.

Various design approaches for truck air suspensions are touched upon to trace the evolution process leading to the present design philosophy which provides roll resistance comparable to steel leaf spring suspension systems.

The suspension described herein, has met all of the design criteria established and, as such, will reduce driver fatigue, equipment and cargo damage. It is well suited to be mated with most trailers with conventional or air suspended axles and equally suited for straight truck applications.

Ride frequency remains essentially constant from light to loaded (197 CPM to 135 CPM) whereas a steel spring suspension has a wide variation (655 CPM to 179 CPM).

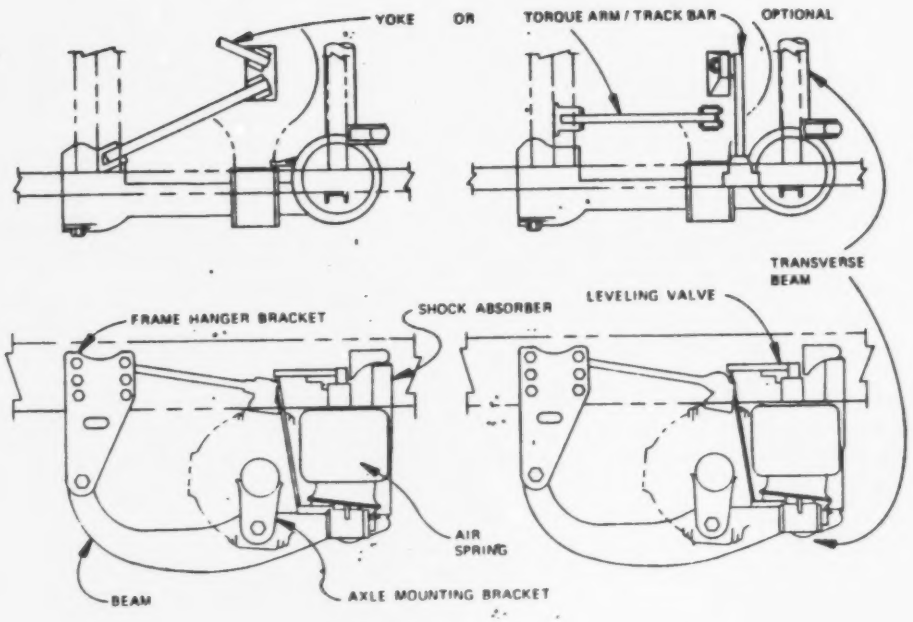
24. DEVELOPMENT OF DRIVE AXLE AIR SUSPENSION FOR HIGHWAY TRACTOR

L. Lee Henry, SAE # 720107

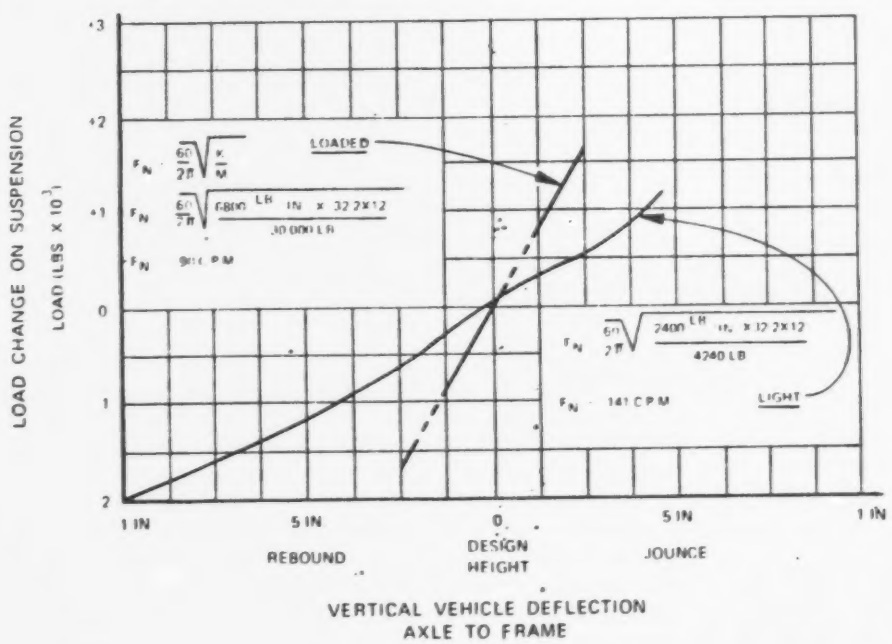
ABSTRACT

Trailer air suspensions have been commonly applied to heavy-duty over-the-highway trailers. Recently, several concepts of drive axle air suspensions have been developed within the industry to various stages. This paper presents concept parameters, product development, and suspension development of the Neway Drive Axle Air Suspension (ARD). Performance ride and handling factors, compatibility, and structural integrity were the established guidelines. (Figure A-14)

The concept analysis shows the functions which must be evaluated for a drive axle air suspension. The ARD concept



ARD suspension



Natural frequency calculations from spring rate test results

Figure A-14 Air Springs, for truck or trailer, single axle or tandem (Neway)

(Cont'd) 24. accomplishes the requirements with the following advantages:

1. Each function is accomplished without compromising other functions or components. For example, diagonal walk can be forced without stressing the axle.

2. The suspension is diagonally flexible yet provides handling stability.

3. It is compatible with frame and axle requirements .

4. Tandem axles are independent with interchangeable hardware for economy and serviceability. Axles can be spread without weight penalty.

5. It fits all service and safety brakes.

6. It is nonreactive for minimum stopping distance.

The ARD concept meets the technical requirements imposed by drive axle applications so that practical hardware is now available which offers the operating advantages of air suspensions to fleets.

25. STABILAIRE TRUCK DRIVE AXLE SUSPENSION: SERIES 400

H.C. Harbers and H.C. Harbers, Jr., SAE # 370652

ABSTRACT

This paper describes the development of a heavy-duty light-weight truck drive axle air suspension for use on single and tandem axles.

A review and evaluation of various air suspensions is made to establish design parameters and their application to the new Series 400 unit.

Mathematical analysis and detail photographs are included.

Having met the conditions of the pertinent mathematical equations, the Series 400 suspension also meets all seven of the significant design criteria established on the onset of this paper.

The new suspension thereby provides a low cost, light-weight, heavy duty suspension, of interest to the industry, with a modular design concept, useful as a basic axle suspension to be used either singly or in tandem.

AIR SUSPENSIONS

26. AXLE LOCATING AND SUSPENSION SYSTEMS FOR COMMERCIAL VEHICLES

Hans Hagen, SAE # 770685

ABSTRACT

In commercial vehicles, simple and inexpensive leaf springs are being proven dominant. This paper will present the alternative solutions, which are available for special purposes.

If compared to conventional versions, these solutions not only excel in regard to special running characteristics, but they also have the advantage of less weight. It may be beneficial to vehicle development if in the future, lighter commercial vehicles contributing to saving energy could become a reality. (Figures A-15 and A-16)

There is no doubt that in commercial vehicles simple, well-proven and inexpensive leaf springs are dominant, yet these explanations show that alternative solutions for special purposes are available, which have already been proven in operation.

In comparison to conventional versions these excel in regard to special running characteristics and they also offer the advantage of less weight. It should be an objective of vehicle development to build even lighter commercial vehicles in the future as a further contribution towards saving of energy. The various axle locating and suspension systems offer some interesting points of departure.

27. KENWORTH AIRGLIDE 100 REAR SUSPENSION

John K. Winslow, SAE # 790768

ABSTRACT

An air suspension has been developed to meet the needs of the Class 8 truck market of the 1980's. This design was developed to satisfy a list of objectives that conform to present and future requirements for a tandem axle rear suspension. Throughout the development program, exhaustive tests were conducted to assure successful performance and minimize the possibility of last minute tooling charges. Dual antisway bars contribute significantly to the dynamic

Since the center of gravity is located quite high on commercial vehicles special emphasis is placed on the problem of roll.

In addition to the choice of spring rate and the installation of additional stabilizers, roll is also influenced by the type of wheel suspension or axle locating system, which determines the position of the roll center, where the body will tilt under the influence of the centrifugal force. The distance between roll center and center of gravity serves as leverage for the pull-out torque and thusly influences roll of the vehicle body in curves.

Fig. 1 shows diagrams of 4 different wheel suspension systems.
The position of the roll center is marked M.
(a) shows a rigid axle with leaf springs,
(b) dual-joint swing axle with helical springs,
(c) double wishbone suspension and coil springs,
(d) axle with trailing arms

Abbreviations:
S_r = wheel track
S_f = spring track (spring centers)
Z = length of swing axle
h_M = height of roll centre above ground

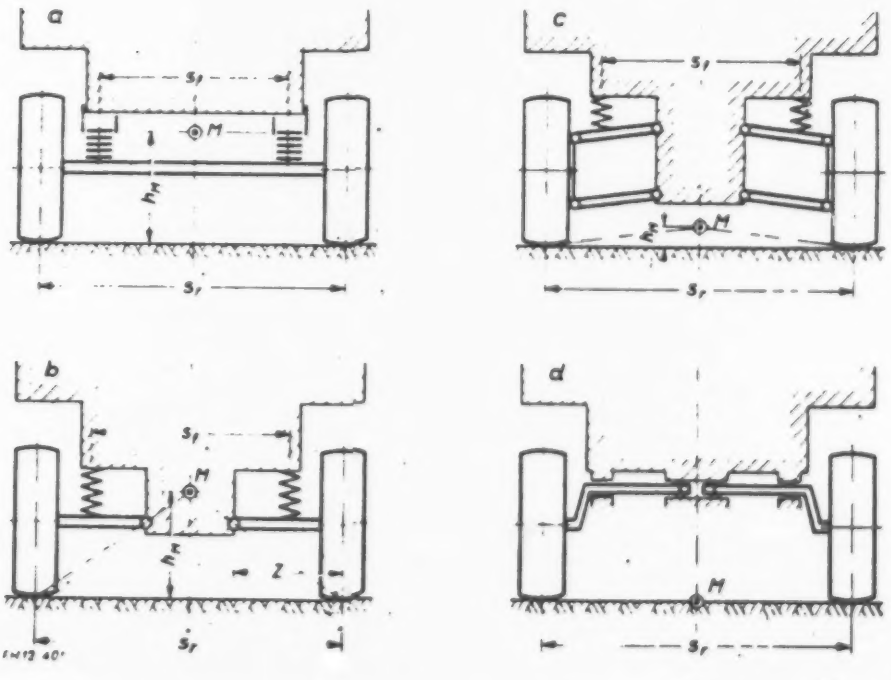


Figure A-15 Position of roll-center M for different axle suspension systems

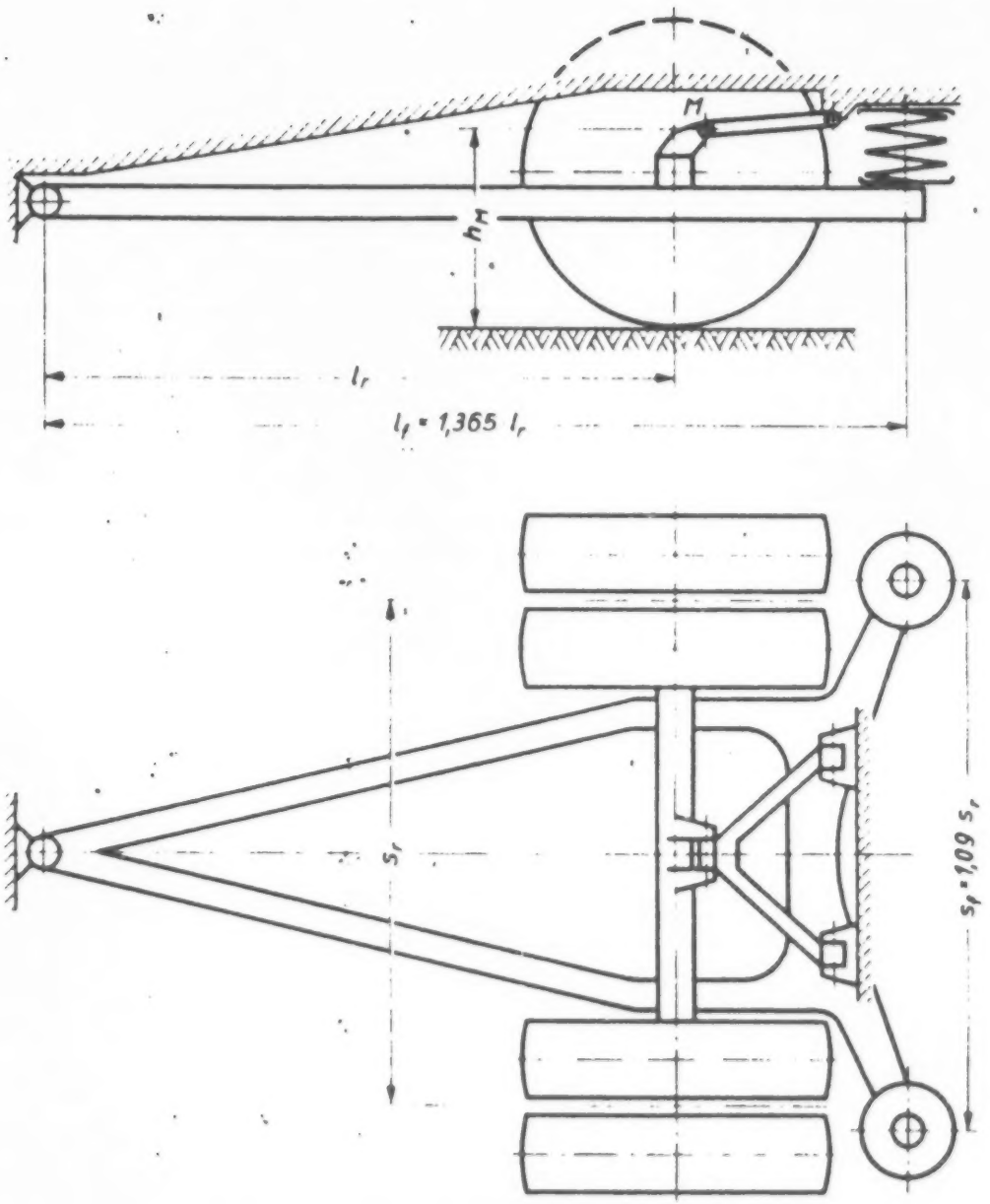


Figure A-16 Rear axle suspension with air springs and wide spring track as used in M.A.N. city-buses

(Cont'd) 27. performance characteristics of this suspension and, along with the full air springing, represent its most significant performance features.

The Airglide 100 development program preceeded along an orderly path of design iterations supported by a thorough test program. Initially, overall design objectives were established and basic concepts were evaluated. As the concept matured, the fine details were developed and refined in a tenacious effort to assure successful achievement of all design criteria. New testing techniques were applied and proven reliable in full scale test track evaluations.

Soundness of the original objectives has been proven by the successful application of the suspension in millions of truck miles of service.

ACTIVE RIDE CONTROL SYSTEMS

28. STABILITY AND CONTROLABILITY OF VEHICLES FOR HIGH SPEED AND HIGH TRAFFIC PERMEABILITY

Yao T. Li, SAE # 660024

ABSTRACT

A general study of the basic requirements of vehicles for individual and public transportation systems leads to the belief that the incorporation of an active suspension system into the vehicle would constitute a major step forward. Various aspects of an active suspension system were scrutinized. Favorable results from an experimental test vehicle confirmed that belief. By incorporating the principle of an active suspension system, a narrow vehicle was proposed for commuter traffic; a utility vehicle for agriculture and military application; and a monorail vehicle for public transportation as well as for super high-speed intercity transportation.

29. THE UNITED AIRCRAFT TURBINE MOTOR TRAIN AND ITS SUSPENSION SYSTEM

Robert H. Shatz and Thomas R. Wheaton, SAE # 660333

ABSTRACT

The turbine motor train designed by United Aircraft Corp. represents a systems approach to high-speed rail service, and incorporates many unique features that will permit operation at speeds up to 160 mph on existing roadbeds with significant savings in trip time and maintenance costs. Special emphasis is given the suspension system used on the UAC turbine powered train. The advantages of this system are that it banks the car body proportionally to the lateral force, allowing higher speeds on curves with comfort equal to or greater than is now encountered. Also, intermediate axles are guided to eliminate the oscillations or truck hunting encountered in conventional trucks. (Figure A-17)

The suspension system used on the United Aircraft turbine powered trains has two unique features. First, the system banks the car body proportionally to the lateral force, permitting higher speeds on curves with comfort equal to or greater than is now encountered.

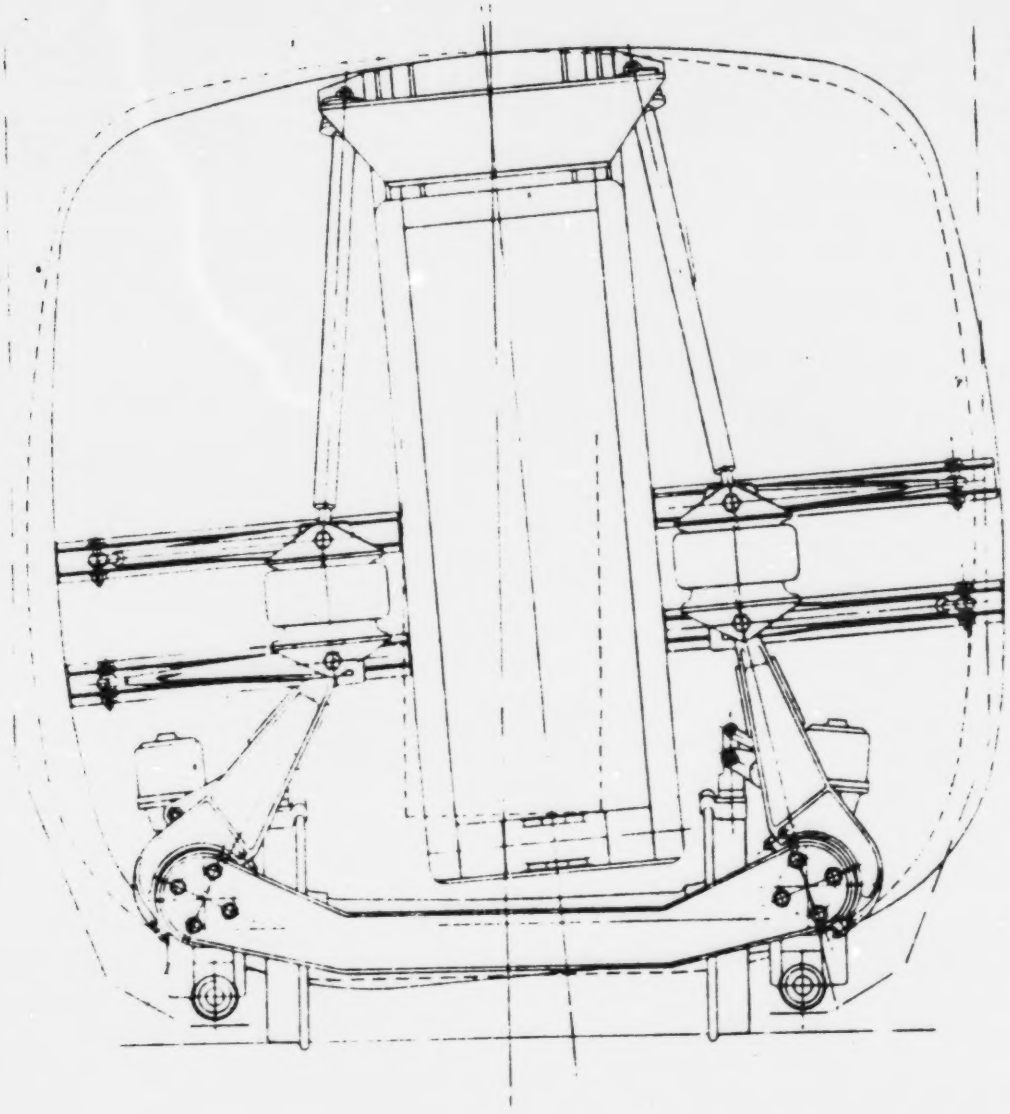


Figure A-17 Turbine train suspension system (United Aircraft)

(Cont'd) 29. Second, intermediate axles are guided to eliminate the oscillations or truck hunting encountered in conventional trucks. These two features will permit these trains to operate at speeds up to 160 mph on today's roadbed, without changing curves or superelevation, at a significant saving in trip time and at a saving of millions of dollars in roadbed investment and train maintenance.

30. DEVELOPMENT OF A HYDROPNEUMATIC SUSPENSION SYSTEM FOR AN EARTHMOVING MACHINE

Paul E. Gies, SAE # 660613

ABSTRACT

The Universal Engineer Tractor (UET), an earthmoving machine, can work as a bulldozer, scraper, rough grader, prime mover, dump truck, cargo carrier, or personnel carrier. Versatility is made possible through the use of a hydropneumatic suspension. Because random variables of terrain and soil are traversed at speeds up to 30 mph, components in the suspension have been subjected to extremely high pressures and to heavy loadings of structural components, due to mechanical feedback. This paper reports on the nature of these problems, describes modifications made to overcome the difficulties, and gives results of subsequent field and laboratory tests.

Several problem areas were encountered during the development of the hydropneumatic suspension for the UET. However, laboratory and field tests have demonstrated solutions that will provide units with the required degree of reliability and maintainability.

31. SOME FUNDAMENTAL LIMITATIONS OF ACTIVE AND PASSIVE VEHICLE-SUSPENSION SYSTEMS

Erich K. Bender, SAE # 680750

ABSTRACT

Some of the fundamental limitations of roll control and vibration isolation are analysed and discussed. Optimum roll responses to a step input in lateral acceleration are derived

(Cont'd) 31. from the calculus of variations. The response show that a pendulous suspension (where the roll center is above the passengers) can be made to exert zero net lateral acceleration on passengers; whereas, a finite lateral acceleration will always be present during maneuvers of vehicles equipped with conventional suspensions (where the roll center is below the passengers). The lower limitation in roadway-induced vibration is presented as a trade-off between vibration and the clearance space between the sprung mass and the roadway. Finally, the substantial benefits accruing from the use of preview control (where the roadway ahead of a moving vehicle is sensed) are presented.

In this paper we have investigated some of the fundamental limitations of the roll and vibration control functions of vehicle suspensions. For the roll mode, if the roll center is below the passengers, there is minimum lateral acceleration that must be tolerated during vehicle maneuvers. On the other hand, for pendulous suspensions, where the roll center is above the passenger level, the lateral acceleration can be made negligibly small.

In the realm of vibration control, the problem of limitations is best viewed as a trade-off between vibration and the clearance space required between the vehicle sprung and unsprung masses or between the vehicle and the roadway. The optimum trade-off is found by minimizing a cost function (of acceleration and clearance expressed in terms of the vehicle suspension) to find the optimum suspension, and then by computing the acceleration and clearance associated with this optimum suspension. The appliction of this technique to fixed configuration systems and to the synthesis of suspensions has shown that:

1. The use of a height-control system is important in reducing the vibration/clearance trade-off.

2. When one is aiming for very low values of acceleration, an active suspension is required.

3. The proper use of preview information on the roadway ahead of the vehicle substantially reduces the vibration clearance trade-off.

ACTIVE RIDE CONTROL SYSTEMS

32. VEHICLE ATTITUDE CONTROL METHODS

Robert Hegel, SAE # 201540

ABSTRACT

As a necessary condition of use, vehicles have suspension systems that must provide reasonable ride comfort and handling and be versatile enough to permit large changes in vehicle loading. Current constraints on vehicle attitude variation allow a reasonable compromise between ride and this variation, using an open loop relationship between loading and attitude. Future constraints on attitudes will cause a change, either in the compromise, or require a more sophisticated relationship. This paper describes the fundamentals of suspension related to vehicle attitude and the details of several closed loop attitude control systems.

Current practice for suspension rates and attitude change with load may not be compatible with future requirements.

If present ride quality is to be maintained, closed loop leveling will be needed. Given this position, the choice to make is between a total system with inherent leveling or a combination system.

As previously mentioned, the load reaction change at the front is much less than the rear and the conflict between the present systems and future requirements seems resolvable using a rear only system. Thus, present levels of ride quality could be maintained with a rear leveling system.

The best choice then, from a cost and reliability standpoint, would be a rear auxiliary system with the obvious cost benefits and also because a total failure of the leveling system would not render the vehicle unusable.

33. THE HYDRAIR II TRUCK SUSPENSION

J.J. France and R.D. Star, SAE # 710708

ABSTRACT

Air over oil, oleopneumatic suspensions were first introduced into the WABCO off-highway HAULPAK trucks in 1957. The HYDRAIR suspension system was developed to

(Cont'd) 33. function as a soft spring and shock absorber for off-highway construction vehicles, providing better operator control, increased vehicle life, and reduced shock loads.

This paper deals with the development of the latest generation of this suspension, which is much simpler in design, has longer life, higher reliability, and still maintains the desirable features contained in the original HYDRAIR suspension. (Figure A-18)

34. ACTIVE RIDE CONTROL - A LOGICAL STEP FROM STATIC VEHICLE ATTITUDE CONTROL

M.B. Packer, SAE # 780050

ABSTRACT

Soft suspension springs are an essential requirement to absorb irregularities in road surfaces without transmitting excessive acceleration forces to the vehicle. Passive attitude control systems compensate for suspension height changes due to static load variations but leave a problem of excessive body motion in response to lateral and longitudinal acceleration. In this paper a system of active ride is described which retains the advantages of a soft suspension, yet controls body pitch and roll due to braking and cornering forces. Handling quality is enhanced by precise control of front to rear roll stiffness. Computed and experimental data is presented to establish fulfilment of the design objectives. (Figure A-19)

The interpretation of measured or predicted data to quantify the quality of vehicle ride is a desirable objective, but analytical techniques often fall short of practical assessment. Cars, several ambulances and a doubledeck London Bus (2) have been converted to Active Ride Control. On demonstrations and service trials there is virtually unanimous acclaim for the improved ride and handling over the standard counterparts.

When first presented with a proposal for Active Ride Control, there is a tendency to dismiss it as a good idea but too complicated. Applications to date have been concerned with the conversion of standard vehicles which may involve a considerable amount of work to accept hydraulic struts.

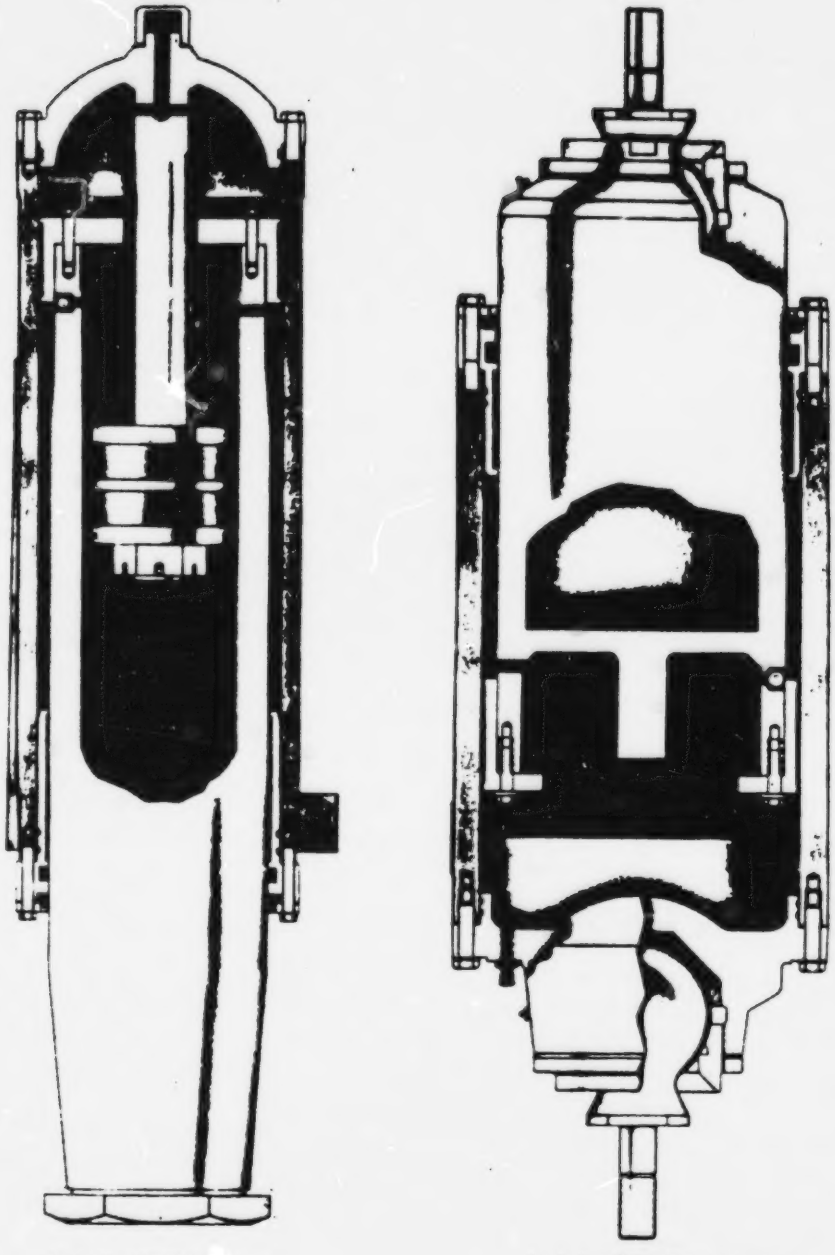


Figure A-18 Hydro-pneumatic spring used on WABCO Haulpak heavy dump trucks

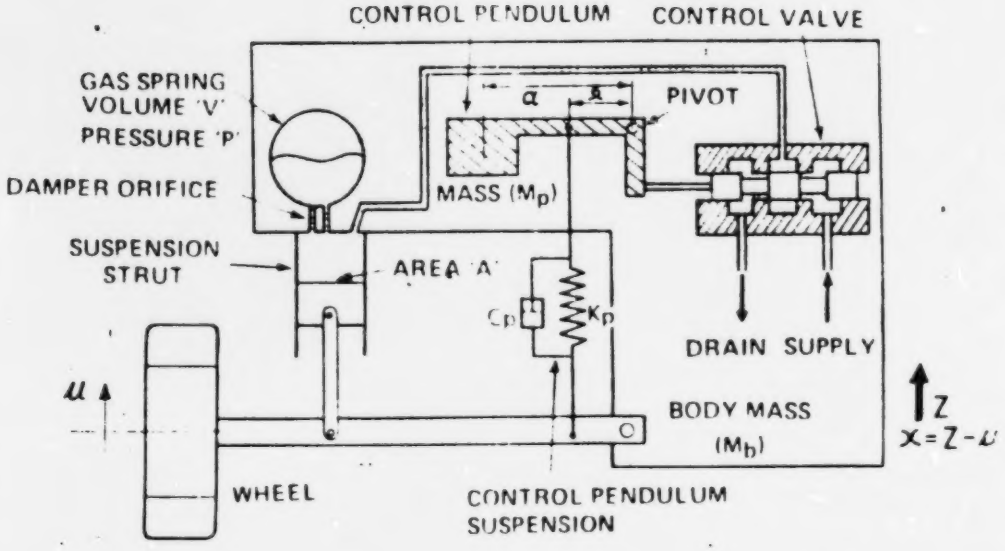


Figure A-19 Active ride control system
(Automotive Products Company)

(Cont'd) 34. The design and production technology for the basic coupled hydraulic suspension and for the application of active ride is well within current practice. By designing the system into a vehicle as initial equipment, the cost of the passive suspension can be equated against conventional equipment. The use of a soft suspension makes the addition of a simple levelling valve at the rear highly desirable to maximize rear wheel suspension travel utilization and avoid headlight dazzle. The additional equipment for active ride control then becomes two control valves and a hydraulic power supply. The cost of the latter can be partially offset by its application to other services, for example, power brakes and antilock devices.

Given these conditions, Active Ride is considered to be a relatively small and logical step from passive vehicle attitude control that eliminates many traditional restraints in suspension design.

35. SELF ENERGIZING HYDROPNEUMATIC LEVELLING SYSTEMS

Theo Meller, SAE # 780052

ABSTRACT

New Hydropneumatic levelling systems with single and twin chambers are presented for application in almost all vehicle makes and types. They are self-energizing and convert the relative movement between axle and body to the advantage of height adjustment. The internal pump work must be understood as load dependent damping, optimizing the settings in relation to load-dependent gas spring rates. It is shown that the units can be designed for similar body frequency within a wide range of payloads.

This essay will assist in solving the problems of soft vehicle suspensions with large load differences. (Figure A-20)

Self-energizing and self-pumping levelling units as single and twin chamber systems have been presented for application in vehicles of all categories. They are capable of solving the problems of soft and comfortable ride with regard to large load differences between unladen and fully loaded. In comparison to systems with external pumps, they are able to achieve a similar sophisticated ride and handling under all load conditions, but at far less cost and with much less complexity.

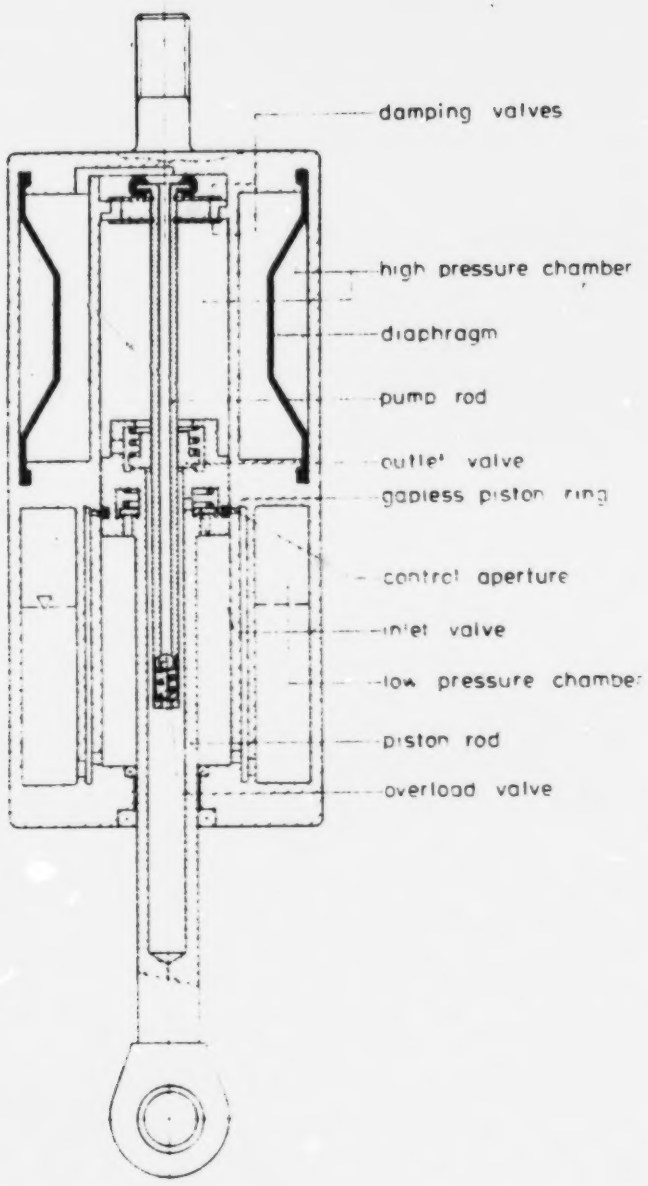


Figure A-20 Self contained active ride control system (BOGE Company)

INTERNAL CONSTRUCTION OF THE TWIN AND SINGLE CHAMBER UNITS

The twin and single chamber elements are telescopic units of a similar external appearance. Their appearance is that of large diameter shock absorbers and they are normally installed in the same place as the conventional vehicle dampers.

However, within each unit, all the normal elements of a conventional type of hydropneumatic levelling systems such as oil pump; oil reservoir; gas accumulator; height sensin device; damping valves and overload valves are completely self contained. Thus these units are able to combine the function of a load depende t hydropneumatic spring together with that of a hydraulic shock absorber. The twin chamber system (Fig. 1.) consists of a double acting piston, the effective area of each side being acted upon by oil, pressurized from the corresponding gas chambers.

COMPUTER SIMULATION & OPTIMIZATION

36. TRUCK SUSPENSION SYSTEM OPTIMIZATION

Bruce D. Van Deusen, SAE # 710222

ABSTRACT

This paper describes a test program and computer simulation aimed at optimizing the riding qualities of a Military tractor semitrailer combination, the Heavy Equipment Transporter (HET). Instrumented testing at the U.S. Army Aberdeen Proving Ground was conducted with a variety of suspension configurations. The test data were recorded on magnetic tape and converted into digital data for computer processing. The test results were correlated with computer simulation. The computer model was then used to perform a sensitivity analysis of various suspension parameters. With rms acceleration at the vehicle frame used as a criterion for optimization, an improved suspension configuration was defined. The techniques for test data analysis and computer simulation are described and preliminary results are presented.

It is possible to optimize the parameters in a given suspension configuration. This optimization is a function of the course severity and the vehicle speed. Interactions of parameter changes must be taken into account since optimum damping is a function of spring rate, etc.

Relatively simple vehicle models yield realistic optimum suspension parameters even though all attributes of the vehicle dynamics are not taken into account.

37. LINEAR SUSPENSION SYSTEM PARAMETER IDENTIFICATION

Glenn A. Jackson and James W. Grant, SAE # 710227

ABSTRACT

A method for measuring spring rate and damping coefficient is necessary for complete laboratory evaluation of a suspension component. This report outlines a technique by which a linear model is adjusted by an analog computer so that its parameters match those of the test specimen. The accuracy of this linear model is good unless the test specimen parameters are very nonlinear.

COMPUTER SIMULATION & OPTIMIZATION

38. LOAD-DEFLECTION CHARACTERISTICS OF VEHICLE SUSPENSION SYSTEMS

Donald F. Livermore, SAE # 670022

ABSTRACT

When a stationary automobile is on a horizontal road, the car and its suspension linkages are in static equilibrium under the actions of gravity loading, road reactions, and internal spring forces. When this same system is acted on by steady cornering and/or axial acceleration loads, in addition to gravity loading, the equilibrium configuration of the suspension will be changed substantially from its gravity-load-only condition, affecting the driving characteristics of the automobile.

This paper presents a general computer-based method for determining displacement relations and equilibrium configurations of mechanisms which are restrained by springs and subjected to steady external loading. The method is illustrated by its application to several suspension systems of varying complexity.

Matrix methods of kinematic analysis offer a basis for powerful general computer programs which can be applied to complex spatial linkage systems for displacement, velocity, and acceleration, and for static force, and equilibrium analyses. Extensions of the methods are being made to the dynamic analysis of linkage systems restrained by springs and viscous dampers. Computer programs based on these methods will be less efficient than those written for specific systems but have the major advantage of almost complete generality.

39. MEASUREMENT OF INERTIAL PROPERTIES AND SUSPENSION PARAMETERS OF HEAVY HIGHWAY VEHICLES

Christopher B. Winkler, SAE # 730182

ABSTRACT

The large size of commercial highway vehicles can lead to significant problems in determining their inertial and suspension properties. New techniques and equipment used in the measurement of these properties have been developed and

(Cont'd) 39. are discussed. Vertical spring deflection behavior, including coulomb friction, for the suspensions of a truck, tractor, and semitrailer are given.

The implementation of recently developed digital computer-based simulation programs for predicting the longitudinal and directional response of heavy highway vehicles required the measurement of key inertial and suspension properties of the vehicles to be simulated. The large size of this type of vehicle introduced significant problems in the measurement of these properties.

New techniques and equipment were developed to solve these problems. Some simple and inexpensive techniques, applicable to inertial testing of bare-frame vehicles, were discussed. The use of additional equipment employed in determining the inertial properties of heavy vehicles fitted with bodies was explained.

Application of the large forces required to produce significant spring deflection in the suspensions of commercial vehicles introduces problems not found in passenger vehicle testing. Some simple techniques used to solve these problems were presented. Data on the vertical deflection characteristics, including coulomb friction, of several commercial vehicle suspensions were given.

40. ANALYSIS AND COMPUTER SIMULATION OF THE FOUR ELLIPTICAL LEAF SPRING TANDEM SUSPENSION

C.B. Winkler, SAE # 740136

ABSTRACT

Many commercial vehicle manufacturers are now using computer simulation as an aid in assuring compliance with FMVSS 121. One particularly important aspect of such a simulation is the analysis of the interaxle load transfer during braking due to tandem axle dynamics.

In this paper, two analyses of the four spring tandem suspension with short load leveler are presented. One, a simplified model, serves to illustrate the mechanism of interaxle load transfer and to identify the design parameters

(Cont'd) 40. which affect this phenomenon. Improved accuracy is obtained by the second model through the inclusion of frictional forces that develop at the points where the leaf springs contact the frame. Comparison of effectiveness test data indicates good agreement between empirical and simulated results when this advanced suspension model is used in conjunction with existing commercial vehicle simulations.

Two analyses of a typical four spring tandem suspension are presented. They are intended to be useful in the analysis and prediction of interaxle load transfer that occurs when this suspension is subjected to braking forces and torques.

Initially, a simplified model is presented. Although this model is known to predict interaxle load transfer in excess of the levels that occur in real suspensions, it serves to illustrate the mechanism by which the phenomenon is generated and to identify the manner in which various design parameters affect the level of load transfer.

Secondly, a more complete, dynamic model is presented. This model includes frictional forces that develop at the points where the leaf springs contact the frame. By contributing to the reaction of brake torque, these forces serve to reduce the level of interaxle load transfer. However, the inclusion of these forces in the formulation introduces indeterminancies into the model. A rationale is presented by which these indeterminancies are removed, thus facilitating an accurate representation of the inter-axle load transfer.

Finally, the results of brake effectiveness tests conducted on an articulated vehicle are compared with the results of full vehicle simulations employing both suspension models. The data indicates the increased accuracy of wheel lock prediction, and, hence, interaxle load transfer attained by the more advanced model.

COMPUTER SIMULATION & OPTIMIZATION

41. SUSPENSION SYSTEM MODELING AND STRUCTURAL LOADING

Robert L. Davis, SAE # 750134

ABSTRACT

The object of this paper is to present an overview of the procedure leading to the selection of suspension system pivot points, show how to resolve terrain and maneuver loads at the tire contact patch to the vehicles' structure, illustrate a few examples of suspension system models used to aid in the solution of ride and handling problems.

The overall purpose of the suspension system analysis techniques described is to:

1. Provide an optimized design with a high confidence factor before drawing release dates.

2. Reduce the total design cycle time and cost reduction of development work required on physical parts.

42. NON-LINEAR MODEL FORMULATION FOR THE STATIC AND DYNAMIC ANALYSES OF FRONT SUSPENSIONS

Kenneth N. Morman, Jr., SAE # 770052

ABSTRACT

A three degree-of-freedom mathematical model formulation for a double-wishbone front suspension is presented which treats the effects of the tire vertical stiffness, the fore-and-aft bushing compliance in the lower arm, the compliance in a steering linkage and the inertia of the suspension links. The model equations are derived retaining all non-linearities associated with large changes in the geometric configuration of the suspension system and are solved within a digital computer program which computes the suspension force and displacement responses to prescribed ground terrain inputs at the tire patch. Results obtained with the computer model are presented and compared with test measurement.

COMPUTER SIMULATION & OPTIMIZATION

43. A SIMPLIFIED METHOD FOR THE IDENTIFICATION OF VEHICLE SUSPENSION PARAMETERS

Donald M. Brueck and E. Dawson Ward, SAE # 770884

ABSTRACT

To simulate vehicle dynamic performance, accurate parameters must be available to relate the vehicle differential equation model to the actual vehicle. This paper presents a simplified method to identify vehicle suspension spring rates, damping characteristics, and unsprung mass inertia properties. The method presented employs a digital computer algorithm to implement and equation error identification technique. A sequence of four laboratory tests was developed to obtain suspension input and response data required in the equation error technique. Each test is of a short duration (less than three seconds) and does not require vehicle disassembly. To verify the technique a test stand employing an electrohydraulic position servosystem was constructed and the test sequence was applied to the rear suspension of a 1972 Pontiac Catalina. When the identified parameters were used to simulate the response of the vehicle suspension to the test input, agreement to within 13 percent of the actual maximum measured response resulted. The results presented in this paper show the potential of the technique to be an accurate, simplified method of obtaining suspension parameters.

The vehicle suspension parameter identification technique presented in this paper shows the potential to be an accurate, simplified method of obtaining vehicle suspension parameters. This identification technique does not require vehicle disassembly or complex calculations of the many components in the suspension system. The actual test duration of less than three seconds and its adaptability to a multiple vehicle test program makes this identification method very efficient. The computation time and memory requirements are also reasonable, especially if much of the flexibility and many of the optional features contained in the algorithms used in this study are eliminated. For these reasons it is felt that the technique merits further study and refinement of the associated hardware.

COMPUTER SIMULATION & OPTIMIZATION

44. AN ANALOG COMPUTER METHOD FOR DETERMINING "g" LOADS AND RESULTING MOTIONS IN AUTOMOBILE AND TRUCK WHEEL-FRAME SYSTEMS

George M. Kurajian and Harold Burr, SAE # 710165

ABSTRACT

A general analog computer procedure is presented for the dynamic analysis of a selected realistic model of an automobile or truck vehicle wheel-frame system. The elements of the model are assigned a set of values based on a pre-selected vehicle, and the model is then subjected to a number of inputs which correspond to test track road disturbances at various speeds. This procedure is successively applied to a number of typical vehicles. Time-varying values of wheel spindle and frame reaction "g" loads, accelerations, and displacements are recorded, and illustrative waveshapes are depicted. Tables indicating extreme values of these quantities are also included.

It is concluded that:

1. The model is a valid one since there was good agreement between the results obtained from the model and comparable results from test track experience as relayed to the authors by colleagues in the industry.

2. The analog computer program was thoroughly checked out internally and also with parameters and inputs which gave compatible, consistent, and realistic data. In particular, at a given time, corresponding values were taken from the specific waveshapes as generally depicted in Figures 7 and 8 for a selected vehicle. These values were substituted into the equations of motion and those equations were completely satisfied.

3. Since there will always be some degree of damping even if the shock absorbers are worn and ineffective (damping effect tires, interleaf damping and other frictional forces are still present), Z - 0 is not realistic. The value of Z - 0.4 seem to be a good value for the average vehicle as concluded by the "bumper test".

(Cont'd) 44. 4. The "g" loads, accelerations, and displacements are considerably higher in the unshocked vehicles as compared with those in the vehicles with shock absorption. This is certainly to be expected, and further supports item 1.

5. The "g" load is defined as the ratio of dynamic load reaction to static load reaction and does not have the same numerical value as corresponding acceleration values. A study of the data and the equations of motion certainly illustrates this most convincingly.

6. For the vehicles selected, and with shock absorption, and subjected to the rough road operation, the maximum "g" loads varied from approximately 1.2 - 1.6 at the frame, and 2.2 - 8.2 at the wheel spindle. The maximum acceleration values varied from 24 - 130 fps at the frame and 400 - 2500 fps at the wheel spindle. All of these maximums occurred during the chuckhole test in each case. These ranges of values along with the maximum displacements are reasonable and realistic.

There is a wide variation in the maximum values of the quantities of interest as one investigates a series of vehicles, indicating that no general or sweeping statements should be made regarding numerical values of "g" loads, accelerations, and displacements. It is, therefore, recommended that this model and analog computer procedure be applied to the particular vehicle under analysis and design.

The authors believe that the model, the computer procedure, and the results and data obtained are valid and give realistic and reliable results and should prove to be useful in the design of automobile and truck vehicles.

45. ANALYSIS OF VEHICLE SUSPENSIONS WITH STATIC AND DYNAMIC COMPUTER SIMULATIONS

Joseph S. Majcher, Rodney D. Michaelson, Arthur R. Solomon, and Jay W. Subheda, SAE # 760183

ABSTRACT

Two types of computer simulations are used extensively by Chevrolet to analyze vehicle suspension systems. The first is a nonlinear static analysis and the second is a linear dynamic analysis. These simulations are used to help

(Cont'd) 45. evaluate proposed suspension designs for loads, dynamic force, transmissibility, and various ride and handling characteristics well before prototype hardware is built and tested. Load outputs from these simulations are input to finite element models to analyze stresses in frames, control arms, and other related vehicle components of interest.

Usage of computer simulation at Chevrolet has added significantly to evaluation of proposed suspensions and vehicle data, a simulation model can be constructed, its kinematics and vibrations evaluated, and its element forces determined. If the elements need further evaluation, element forces calculated are applied to detailed finite element models to study local deformations and stress distributions. Although prototypes will continue to be tested for design validation, prototype re-design will be reduced in that design proposals can be realistically evaluated by analytical methods.

As design and performance requirements become more stringent, simulation will play an ever increasing role in design guidance. As computer and simulation technology increase, simulation developmental manpower efforts will be reduced, allowing more emphasis on detailed analyses. Time sharing systems and interactive computer graphics are increasing capability and versatility. The advancement of knowledge about nonlinear dynamic analysis is gaining impetus, and perhaps soon, nonlinear vibration problems will be solved as easily as linear ones are presently.

Experimental testing should complement simulation. More exact stress and fatigue criteria for materials will be needed, particularly in the vibrating environment to allow quick design evaluation. The field of material and structural damping characteristics needs continuing work to ensure accurate values in simulation models.

46. EFFECTS OF TIRES ON TANDEM TRUCK RIDE AND VIBRATION PROBLEMS - SUMMARY

Bruce D. Van Deusen and Stanley H. Backaitis, SAE # SP-260

ABSTRACT

The authors summarize information on effects of tires on tandem truck ride and vibration problems. An appraisal of research and a request to face the challenge of acquiring better engineering measurements of vehicle vibration are given.

47. RIDE COMFORT ASPECTS OF HEAVY TRUCK DESIGN

J.I. Kiparits, J. Aurell, and E. Andersers, SAE # 781067

ABSTRACT

The design of heavy trucks with respect to the ride comfort poses two classical problems. One is the articulated vehicle problem and the other is the "jumping ride" problem caused by elastic vibrations of the frame. The two problems have been identified in field investigations. The vibration isolating system of a truck has been analyzed by means of mathematical simulation. Mathematical models of different sizes have been used to examine the influence of different parameters. The damping, cab suspension and frame vibration are discussed in detail. Efforts to optimize the system have been made. These results and the results from measurements, such as impedance tests and road tests, have been applied in the development of a COE heavy truck family. The final judgement of the ride comfort of these trucks is also presented.

It is concluded that:

1. A soft cab suspension improves the ride comfort in the vertical as well as in the longitudinal direction, but it does not eliminate the articulated vehicle problem.

2. A soft cab suspension eliminates the frame vibration dependent ride problem.

3. The damping is of very great importance for the ride comfort. The negative influence of friction must be underlined.

(Cont'd) 47. 4. It is difficult to judge different designs only based on calculations because the Quality Index is very much dependent on the damping.

5. There is a need for a numerical method that makes it possible to optimize the damping and calculate the Quality Index for a system with many degrees of freedom.

48. THE HIGHWAY TRUCK RIDE PROBLEM

William F. Le Fevre, SAE # SP-260

ABSTRACT

Discussion of improvement of truck ride, chiefly concerned with driver and passenger comfort related to road condition.

The kinds of natural vibrations in vehicles which determine the quality of ride are discussed first, and then the sources of forces, both outside and within the vehicle in operation, which initiate the vibrations and establish their magnitude of motion.

In this discussion of ride of tandem drive tractors used in highway service, consideration has been given to the vibration characteristics of the tractor-trailer system which influence driver ride in the elements of the tractor which affect ride have also been discussed as well as both the internal and external forces which set these vibrations into motion.

By examining the factors involved in highway truck ride, we begin to recognize the suspensions of the tractor and trailer as being the heart of the ride problem. We need lower rate spring rates especially in tandem suspensions than are available in commonly used suspensions. Inseparable from requirements of low rate is the need to eliminate friction, or at least to reduce it to small amounts so that suspension with adequate deflections are free to operate. Reduced spring rates provide desirable reductions in pitch and bounce frequencies while at the same time providing isolation of the sprung masses of the tractor and trailer from external forces which cause objectionable ride vibrations as well as from exiting forces in the unsprung masses.

(Cont'd) 49. Refinement in other features such as seating, cab mounting, frame flexure, drive line vibration, fifth wheel connections, and such, contribute to the ultimate improvement in driver and cargo ride. However, none by itself can substitute for the required improvements which must be made in tractor and trailer suspensions. Neither can the ultimate in ride be achieved in the tractor alone without adequate treatment of trailer suspensions.

Investment in equipment that produces improved ride can mean a real dollar return to the truck operator. One operator has reported a significant reduction in damage claims in one year by installing premium suspensions in only one-third of his trailers. At the time he had developed a market hauling delicate electronic equipment. With these results, the operator is planning to install better suspensions in all his trailers. The reported cost reductions do not include the reduction in maintenance through reduced vibration damage to the truck equipment. Certainly this experience could be repeated over and over again to the benefit of the operator. No less important are the benefits to comfort and safety for the driver, for the basic improvements in ride for the cargo will also contribute to driver ride.

48. TRAILER RIDE EFFECT ON TRACTOR AND CARGO

Eugene Chosy, SAE # SP-260

ABSTRACT

New suspension springs offer the possibility of eliminating severe tractor pitch in a vehicle combination. Experience shows that, in some cases, reducing semitrailer suspension frequencies will accomplish this.

Test data also covered the ride affect of semitrailer suspension on cargo and tractor cab. Effect on cargo at three points in open top van semitrailer and tractor cab is covered.

50. FRAME BEAMING, FIFTH WHEEL LOCATION - SPECIAL BODY MOUNTING AND LOADING PROBLEMS

A.R. Smith, SAE # SP-260

ABSTRACT

Discussion of four factors pertinent to any overall ride evaluation. These factors are frame beaming, fifth wheel location, special body mountings, and variable loading conditions on tandem truck and tractor ride.

(Cont'd) 50. The methodology for measuring the characteristics of these factors is reviewed and practical solutions for improved ride are given.

51. DRIVETRAIN INFLUENCE ON TRUCK TANDEM RIDE

W.T. Trisler and W.E. Rice, SAE # SP-260

ABSTRACT

The construction of superhighway systems will increasingly influence the need for ride improvement. Many basic principles, such as universal joint operating principles, propellar shaft runout and balance, handling and shipping and others, will become more important.

This paper is a discussion of the principles which will have to be considered in order to provide more comfortable ride.

52. ELIMINATION OF TRUCK CAB VIBRATION INDUCED BY TORQUE VARIATIONS OF A 4-CYCLE 6-CYLINDER DIESEL

D. F. Stimeling, SAE # SP-260

ABSTRACT

This case history explains a practical test procedure which led to the successful solution of a cab vibration problem through the development of a new engine front mounting arrangement. It also substantiates the importance of considering the dynamic properties of materials used in vibration isolation. The new engine mount provided the required freedom for transverse vibratory displacement of the engine, thereby keeping much of the engine vibration out of the frame rails and the cab.

The installation of the revised engine front mount crossmember with rubber isolated trunnion mount caused a reduction of the vibration amplitude in the major axis of 95% at the frame and 60% at a representative location in the cab. This reduction was such that annoying vibrations of the steering wheel, seat, cab, and mirrors were no longer evident.

(Cont'd) 52. The amount of vibration reduction caused by the use of softer engine rear mounts was small and of doubtful practical benefit considering the degree of compliance required.

53. THE IMPORTANCE OF DYNAMIC TESTING OF ELASTOMERS

R.S. Auda and R.M. Cardillo, SAE # SP-260

ABSTRACT

Certain dynamic methods of testing enable the characterization of elastomeric materials for vibration control in terms of engineering data obtained on fullsized vehicle parts. These dynamic methods are discussed along with several of the traditional rubber test methods currently used in specifying rubber.

The discussion emphasizes the usefulness and limitations of the various test methods. Comparisons are made with different elastomers and rubber compounds, showing how the more sophisticated dynamic tests can detect behavior differences, whereas the traditional test methods would have indicated equivalencies. Also, data are shown that correlate actual ride evaluation with dynamic test results.

CHASSIS EFFECTS ON TANDEM RIDE - A SUMMARY

R.N. Janeway, SAE # SP-260

ABSTRACT

Summary of thinking on analytical approach to the highway truck problem and the effects of any combination of suspension conditions. The author attempts to coordinate the various contributions into a set of guidelines for continuing ride developments.

55. ENVELOPING CHARACTERISTICS OF TRUCK TIRES - A LABORATORY EVALUATION

S.A. Lippmann, W.A. Piccin, and T.P. Baker, SAE # SP-260

ABSTRACT

This paper describes the enveloping properties of truck tires as consisting of two components of force, one in the vertical direction and another in the direction of travel.

(Cont'd) 55. The responses to irregular surfaces are mathematically accountable in terms of the response to a step in pavement elevation. Tires may therefore be readily characterized, in general, through their reactions to step functions. Curves display the differences in enveloping properties available in the 10.00-20 size on the open market.

56. RIDE CHARACTERISTICS OF THE WIDE BASE TIRE

R. P. Powers and W.E. Moore, SAE # SP-260

ABSTRACT

The relatively new wide base tire has a number of distinct advantages over duals. One of these, improved ride, is discussed. Data taken under static conditions shows the spring rate for the wide base tire to be substantially less than for duals under fully loaded conditions, with less difference appearing under lightly loaded conditions. This, it is believed, partly explains the tire behavior as it relates to impact absorption and bounce under dynamic loaded conditions, wherein an exaggerated bump condition is introduced. Over rough concrete, also, the data shows greater impact absorption for the wide base tires than for duals.

In summary, the wide base single tire has many applications. From a ride standpoint, it has a substantially lower spring rate than duals. Like any spring which is softer than another, it also has greater deflection and a lower basic frequency. These characteristics combine to give a tire which absorbs more road shock and provides better ride for both cargo and driver than is possible with duals. This relatively new tire is here to stay. Its advantages are many. As more trucks are designed to exploit these advantages, the tire's importance to the trucking industry will become even greater.

57. EFFECT OF TIRE UNIFORMITY ON RIDE - WIDE BASE AND REGULAR TRUCK TIRES

D.H. Carson, SAE # SP-260

ABSTRACT

The uniformity characteristics of wide base and conventionl truck tires are established and the effects on ride on unbalanced and radial runout in both types of tires

(Cont'd) 57. are evaluated. Tire profile relationship--aspect ratio--is related to ride characteristics to establish the directional influence of a change in tire profile on vehicle ride.

58. FACTORS AFFECTING PERFORMANCE OF HUBS, DRUMS, WHEELS, AND RIMS ON TRUCK TRACTORS AND TRAILERS

W. C. Long, SAE # SP-260

ABSTRACT

A compilation of vibration producing elements in large and medium truck and trailer wheel, hub, and drum assemblies. Current values and practices are shown, along with hitherto unpublished data from major United States manufacturers.

1. Physical dimensions and tolerances of wheels, rims, hubs and drums improved greatly in all types during the last two decades.

2. No basic research has been done to evaluate fully the effect of lateral runout in wheels, rims, and tires at loads and speeds currently encountered, or projected, for trucks and trailers.

3. A variety of opinions exists regarding the true effect of static and dynamic balance forces, radial runout and dynamic runout.

3. A variety of opinions exists regarding the true effect of static and dynamic balance forces, radial runout and dynamic runout.

4. Further research and analysis is necessary in the area of wheel assembly characteristics covered by this paper.

TEST FACILITIES

59. A TEST FACILITY FOR THE MEASUREMENT OF HEAVY VEHICLE SUSPENSION PARAMETERS

Christoper B. Winkler and Michael Hagan, SAE # 800906

ABSTRACT

A new facility for the measurement of the compliance, kinematic and coulomb friction properties of heavy vehicle suspensions is described. The facility may test single or tandem and front or rear suspensions. Test procedures for measurement of vertical and roll rates, kinematic and compliant steer effects are presented. Qualitative findings are discussed and example data is appended.

This paper reports on a new and unique facility for the measurement of the compliance, kinematic, and coulomb friction properties of heavy vehicle suspensions. A general description of the facility and its major, functional elements has been presented. Various test methods have been discussed and a review of qualitative findings to date was given. Detailed descriptions of machine elements, and specific suspension data is presented in appendices.

60. SYSTEMS DYNAMICS DEPARTMENT CAPABILITIES

Chrysler Corporation, Catalogue # Nil

ABSTRACT

The Systems Dynamics Department of the Chrysler Defense Division conducts a variety of mathematical analyses and evaluations which lend support during the evolution, modification and optimization of systems - primarily military vehicles - developed by the Division. These activities, while focused chiefly in the dynamics of systems, cover a wide range of areas such as ride dynamics, automotive, soft soil performance and mission performance. Although much of the work is mathematical in nature, a thorough knowledge in each field is acquired through contact and communication with the development engineers and others, and through interfaces with the physical systems themselves. In fact, the Department often provides assistance in the planning and running of laboratory and field tests and subsequently reduces, analyzes and presents the resulting test data.

Much of the work done by the department involves mathematically modeling the physical systems by means of

(Cont'd) 60. computer programs. A description of these mathematical models provides a good indication of the variety of fields covered in Systems Dynamics Department activity.

The Systems Dynamics Department has made major contributions to the technology of mobility production. These contributions are particularly significant in ride dynamics and automotive performance where leadership in both industry and Government has been established. Chrysler was the first industry to use the powerful new AMC-71 model to guide the design of practical new military trucks with outstanding mobility performance. Continual refinements and validations of the Systems Dynamics models insure sustained leadership in the field of vehicle mobility.

61. VEHICLE SERVICE LOADS

C. Crane, D.C.H. Bingham and B.G. Bevan, MIRA Research Report

ABSTRACT

The loads in vehicle suspension components have been under investigation by the Association for a number of years. Several reports have been published describing the instrumentation and analysis techniques.

The majority of the results published have been from tests carried out under strictly controlled conditions and concerned the variation of load with speed over straight homogeneous road surfaces, where the effect of factors induced by the vehicle driver such as cornering, braking and acceleration have been deliberately excluded.

This report extends the scope of the work in the light of knowledge attained to cover more normal driving patterns and the results contained are from tests over public roads, where no restrictions have been placed on the vehicle driver.

A number of reports were published by the Association between 1964 and 1970 on detailed analysis of the response of motor car suspensions to road surface roughness in tests where the effects of cornering, hills, braking and changes in road surface along the route were eliminated deliberately. This report deals with extending the analysis to conditions closer to normal driving patterns in which all these factors are included. There are two aspects to be

(Cont'd) 61. considered, the first of which is the measurement of the effects of the low-frequency factors involved in the first three conditions, and the other is dealing with the effects of changes in road surface along the route.

For the first problem, whole body accelerations of the vehicle, measured at its Centre of Gravity were correlated with the loads produced in the suspension by low-frequency maneuvers in service. For the second, the application of statistical analysis to the suspension loads originating from road surface roughness was extended by identifying the types of road surfaces encountered along the route.

The main conclusion reached was that when due precautions are taken it is possible to calibrate one vehicle thoroughly and then assess the routes which it or similar vehicles have been driven over from fairly simple recordings.

62. THE INFLUENCE OF STEERING AND SUSPENSION SYSTEM DEGRADATION ON VEHICLE LIMIT PERFORMANCE

P.S. Fancher, R.D. Ervin, and L. Segel, SAE # 740149

ABSTRACT

The influence of degraded steering and suspension components on open-loop vehicle performance at the limits of tire-road frictional coupling is examined in this paper. The major conclusion obtained is that, with the exception of the shock absorber in certain maneuvers, the range of limit performance exhibited by new cars, as derived from design differences, is much larger than the in-use changes in limit performance of individual vehicles deriving from degradation of steering and suspension system components. This result should lead to future studies in which:

1. The influence of steering and suspension system degradation in the nonlimit regime of vehicle operation explained.

2. Equipment for on-the-vehicle evaluation of suspension damping is investigated.

3. Greater emphasis is placed on the degradation of tires and brakes.

Based upon the observations, analyses, computations and test measurements performed in this study, the following conclusions were drawn. It must be emphasized that these conclusions relate component degradation to limit performance, and not to the sublimit domain in which most normal driving is conducted:

1. The range of limit performance exhibited among new cars, deriving from design differences, is much larger than the in-use changes in performance of individual vehicles deriving from degradation of steering and suspension system components.

2. The principal suspension component whose likely degradation can be shown to influence limit performance is the shock absorber.

(Cont'd) 62. 3. Shock absorber degradation contributes a deterioration in limit performance principally under conditions which excite vertical motions of the unsprung masses, eliciting the brake hop, wheel hop, and axle tramp phenomena which result in net losses in tire shear force.

4. Degradation in shock absorber performance can arise from a number of characteristically differing mechanisms. Given that these degradation mechanisms are manifested by coulomb friction, free travel, hysteretic effects, and other complex nonlinearities, it appears inadequate and thus inappropriate that shock absorber condition be represented by such simplistic characterizations as percent effectiveness.

5. Indeterminancies of front wheel steer angle which arise due to lash in wheel bearings, ball joints, tie-rod ends, or steering gearbox, whether taken singly or in combination, do not exhibit a first-order influence on vehicle limit performance.

6. Misalignment of front wheels, to the virtually maximum level achievable, has been shown to contribute a significant alteration in limit lange change performance, as measured by an open-loop technique.

7. Vehicle limit braking performance, both in straightline and curved-path conditions, is more severely degraded by the presence of brake imbalance can possibly further deteriorate limit braking performance beyond the level obtained with brake imbalance alone.

8. Mass unbalance of the road wheels has been shown to have a negligible influence on limit braking and steering performance.

9. The limit cornering capability of passenger vehicles has been shown to be insensitive to degradation in steering and suspension systems.

10. The rollover resistance of passenger vehicles can be reduced through degradation of shock absorbers, and in certain cases may also be influenced by the addition of front and misalignment.

(Cont'd) 62. The many degraded system conditions which contributed relatively inconsequential adjustments to limit behaviour are, nevertheless, known to involve factors which impose a challenge to the low level lane-tracking task. A level of driver attention may be required under such circumstances, which, giving rise to driver fatigue, constitute a safety hazard of substantially greater dimension than that deriving from the marginal deterioration of limit performance properties.

Degradation categories in which limit performance sensitivity is felt to be pronounced include deterioration of tires and brakes. In this study a tire wear/side force relationship was identified which bears on limit performance to a much exaggerated degree, in comparison with steering and suspension degradation influence. Although the type of wear considered was that which derives from severe cornering, it is felt that this data and other data clearly indicate the need for an examination of limit maneuvering properties as influenced by the level or normal tire wear and its distribution around the vehicle.

With regard to the implications bearing on vehicle inspection which derive from the findings of this study, it is clear that the inspection for shock absorber degradation is an activity which merits attention. As recommended by the two major preceding studies of steering and suspension system degradation, (6,7), the need for an effective assessment of the running gear is recognized. A rigorous evaluation of apparatus for measuring suspension damping on the vehicle should be undertaken, not only for the sake of advancements in periodic motor vehicle inspection practice, but also for application by the vehicle maintenance and servicing enterprise as well.

63. THE ROLE OF STEERING AND SUSPENSION DEGRADATIONS AND FAILURES IN ACCIDENT CAUSATION

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ABSTRACT

Despite inherent difficulties of assessment, accident investigation can provide useful estimates of the role of steering and suspension degradations and failures in causing accidents; studies conducted by the Indiana University Institute for Research in Public Safety indicate that such factors probably account for no more than about 5% of

(Cont'd) 63. accidents, and other causation studies record similarly low involvement percentages. However, neither the influence of different original equipment capabilities nor the role of degradations as a source of driver fatigue has been adequately considered. Another group of studies has shown that degradations in steering and suspension components can adversely affect vehicle handling, and that such degradations are common in the vehicle-in-use population.

Based on accident causation studies conducted by IRPS and a review of other recent studies which have dealt with the subjects of accident causation and the effects of steering and suspension degradation on vehicle limit and nonlimit handling response, the following summary statements may be made:

1. Steering and suspension problems of all kinds (both degradations and failures) were definite causes in only one of 215 accidents (0.5%) investigated by IRPS in-depth teams during recent project phases. Altogether, steering and suspension problems of all kinds were identified as at least possible causes (that is, as definite, probable, or possible causes) in 11 of the 215 accidents (5.1%).

2. Steering and suspension failures are indicated to be extremely rare occurrences. Of 215 accidents investigated by IRPS-depth teams during recent project phases, only one failure (an alleged lockup of a steering gearbox) was noted, and this was only at the "possible cause" assuredness level. Other studies report similarly low involvement percentages. Accident-causative failures, tie-rod failures, ball joint shank failure, loss of idler arm retaining nut, idler arm pin breakage, pitman arm failure, leaf spring breakage, shock absorber clamp failure, and an A-arm/trunnion connection failure. Data are not adequate to rank these in in importance.

3. IRPS data indicate steering and suspension degradations to have been a definite cause in only one of 215 accidents (0.5%) investigated by the in-depth teams during recent project phases. Altogether, steering and suspension degradations were at least possible causes (that is, were definite, probable, or possible causes) in eight accidents (3.7% of total). Free play and/or looseness in the steering system was the predominant degradation implicated in IRPS data.

(Cont'd) 64. 4. Assessing the role of steering and suspension degradations in accident causation is inherently difficult, and except in unusual cases involvement cannot be established with precision. However, useful estimates of involvement can be developed by assessing such degradations as "possible causes" where they are present, potentially relevant, and their involvement is not negated by other evidence or circumstances. IRPS causation studies have embraced this approach.

5. Neither the IRPS study nor other causation studies which have been performed appear to have accounted for the causal role of steering and suspension degradations as a source of driver fatigue and inattentivenes; the possibility that degradations influence causation in this manner requires further examination.

6. Neither the IRPS study nor other causation studies conducted to date appear to have significantly examined the influence of vehicle design and as-manufactured handling capabilities on accident prevention, and hence should not be interpreted to indicate that improvements in design would not be effective in preventing accidents.

HANDLING

64. REAR SUSPENSION ISOLATION - ITS EFFECT ON RIDE AND HANDLING

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ABSTRACT

This paper discusses rear suspension isolation requirements of leaf spring and coil spring suspensions, covering in the latter both body frame separate and body frame integral designs.

In the transition form a leaf spring to a coil spring suspension and further to the coil suspension of an integral body and frame structure, isolation element sizes have increased. They have introduced problems in handling and shake control due to increased flexibility, and in ride and noise isolation resulting from insufficient flexibility. The resultant element design is thus a compromise, such as that covered here through the development of the Oldsmobile suspensions of the past few years.

65. THE HANDLING PROPERTIES OF LIGHT TRUCKS

D.J. Bickerstaff, SAE # 760710

ABSTRACT

The purpose of this paper is to discuss handling in the context of those operational variables and vehicle chassis considerations which are most significant in affecting the handling properties of light trucks.

In discussing handling for normal driving the Cornering Compliance Concept is used to combine the most significant parameters in a simple lumped parameter model. Limit handling performance and the mechanics of rollover are discussed in the paper.

It is observed that exposure to limit handling maneuvers is unlikely to occur in normal driving. The significance of vehicle handling properties to highway safety is an unknown at this time.

(Cont'd) 65. In determining their handling characteristics, Light Trucks were shown to require careful consideration of the effects of load and its distribution.

The Cornering Compliance Concept was used to indicate how the total Understeer Coefficient was affected by various critical chassis and tire parameters and how wheelbase, velocity, and the Understeer Coefficient affect the Steering Sensitivity.

Tire cornering stiffness, a major factor influencing cornering compliance, was shown to be significantly affected by load and vehicle parameters (roll couple distribution) which can change the load.

The various mechanisms which affect the Corner-Cornering Compliance were described with the emphasis on the magnitude of changes which may be made by changing vehicle design variables.

Transient response characteristics were related to steady state Cornering Compliance and Understeer characteristics, faster response times associated with more understeer.

The mechanisms affecting rollover were discussed in terms of both the lateral acceleration and tripping that although some vehicle configurations could not be rolled over on smooth pavement, all vehicles could be "tripped" to rollover at velocities well within their normal operating domain.

It was demonstrated that in normal driving, vehicles are usually operated in a lateral acceleration domain substantially lower than the limit of tire adhesion would permit in cornering. The lateral acceleration capabilities required for normal driving will not produce rollover.

It was indicated that no absolute agreement on ideal handling properties exists at this time, either in terms of subjective assessment or highway safety.

A concept was proposed, the Cornering Compliance Concept as a useful tool to augment existing Industry Evaluation Techniques in determining vehicle handling properties at the design stage.

66. THE STATIC DIRECTIONAL STABILITY AND CONTROL OF THE AUTOMOBILE

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ABSTRACT

An approach to the study of static stability and control of the automobile, that is based on a concept of tethered vehicle testing using a yaw constraint, is described. The supporting theory, however, stands alone as a method of analysis. Graphical methods are developed in which sideforce, yaw moment, and lateral acceleration coordinates define performance plots. These plots reveal certain well-known steady-state performance parameters as well as a new one that defines static stability quantitatively. The theory is presented for the linear automobile with tire sideforce saturation but is applicable, by testing or computer simulation, to the non-linear case.

A new method for analyzing the stability and control of automobiles has been described. The method is based on determinations of the forces and moments which can be developed by the vehicle in the quasi-static condition without the restriction of it being fully trimmed. In this sense, it follows the techniques used in aircraft and ship design for the evaulation of stability and control capability. The method can be applied to the determination of control parameters of the more traditional form, but it also permits the extension of these to provide insight into behavior over the complete operating envelope.

In this introductory paper, emphasis has been placed on the background and development of the approach. Simplified models have been used in most cases to aid in its explanation. Numerous examples have been given to illustrate various aspects of its development and use, but a thorough discussion of the many applications for which it appears to be suited will have to be left to a future paper. At this point, it has been shown that the method distinguishes among stability, control, and trim considerations and that maneuverability characteristics can be defined over the total range of performance.

(Cont'd) 66. In the long run, the value of the approach is thought to lie in the performance portrait and the ability to interpret capability diagrams at various operating conditions. This will require a learning process in which the meaning of the values of slopes, spacings, intersection angles, and changes in the parameters within the diagram can be related to stability and control characteristics. Changes in size and shape of the envelope (as functions of design and operating conditions), identification of the type of diagram best-suited for particular purposes, and uniqueness of changes characteristics are all part of this next step.

67. THE USE OF THE NATO REFERENCE MOBILITY MODEL IN MILITARY VEHICLE PROCUREMENT

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ABSTRACT

The US Army Tank-Automotive Command (TACOM) has adopted a new policy with respect to all initial vehicle acquisitions. It has been decided to specify off-and-on-road mobility requirements by means of a "standard" quantitative methodology and to perform subsequent concept analyses by means of this methodology only.

Prior to 1972, mobility specifications contained imprecise requirements such as "it has to be as mobile as the M113 in mud, snow and sand". However, since 1972, specifications frequently included performance criteria which were given in quantitative terms. The method for computing these characteristics, however, has not been fixed until now.

The objective of this paper is to review the methodology selected by TACOM, namely the use of a comprehensive computerized mobility simulation called the NATO Reference Mobility Model (NRMM), and to present the Command's plans to implement this policy.

POOR

QUALITY

ORIGINAL